INTERNATIONAL COURT OF JUSTICE

CASE

CONCERNING THE GABČÍKOVO-NAGYMAROS
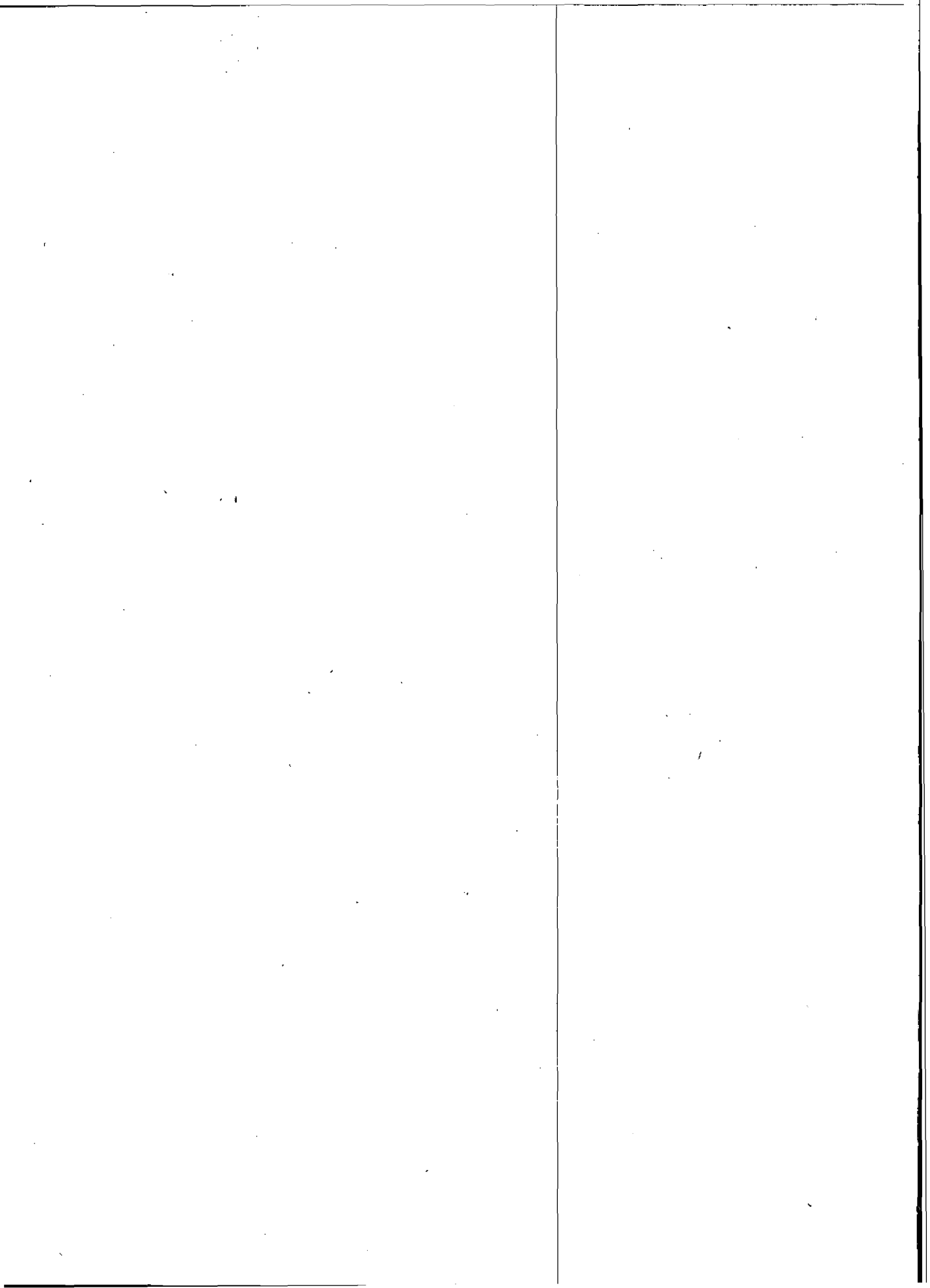
PROJECT

(HUNGARY/SLOVAKIA)

COUNTER-MEMORIAL

OF THE REPUBLIC OF HUNGARY

ANNEXES

SCIENTIFIC EVALUATION OF
THE GABČÍKOVO-NAGYMAROS BARRAGE SYSTEM
AND VARIANT C

VOLUME 2

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CHAPTER 1

INTRODUCTION

The Gabčíkovo-Nagymaros Project represented a massive development, the implementation of which could create a serious environmental impact along a 250 km stretch of the Danube. This area encompasses a rare and endangered ecosystem and contains Central Europe's largest underground aquifer. This is not merely a landscape of beauty and rich historical significance, but is the primary source of water for Hungary's capital city.

The assessment of the relative importance of economic benefits and environmental impacts is ultimately a political issue. However, it is the task of science to provide an objective assessment of the potential consequences of any project, and to identify any uncertainty in that assessment and risks associated with it. Political acceptance of risk is fundamentally related to the potential significance and level of damage. In the present case, the assets at risk are obviously of national strategic importance and, in a wider context, are of European significance.

For the Original Project, the scientific issues are particularly complex, multi-faceted yet strongly interrelated. The purpose of this Science Evaluation is to present these issues with clarity, to explain the functioning of the natural system, to indicate the potential impacts of the Original Project and the associated uncertainties, and to describe the observed short-term and potential long-term consequences of Variant C.

On both sides of the issue, there has been, and continues to be, a large investment of resources in the evaluation of the Project's various consequences. The availability of new data, new methods, and the hindsight of experience of Variant C have heightened our awareness of the processes involved. There is therefore also a historical perspective to this document. The extent to which risks were perceived and quantified in 1990 is shown, and progress in reducing the uncertainties of impact assessment reported. The topic of environmental impact assessment is itself discussed, in order to place the evaluation of the project in its historical (and rapidly changing) context.

Underlying the project is the recent history of bed degradation, both at Bratislava and elsewhere. Here the morphological development of the Danube is of fundamental importance. It is necessary to understand the causes of bed degradation to develop an appropriate solution, and to consider all potential management options, both structural and non-structural. In *Chapter 2*, the history of morphological change is reviewed, causes of recent degradation identified, and alternative solutions discussed. Morphological change is intimately connected with

river flow and sediment transport, and so this chapter also incorporates a discussion of sediment dynamics, flood management, and the hydraulic constraints on navigation.

The interrelationship between surface water and groundwater is a crucial issue in terms of understanding not only the natural, physical, chemical, and geological functioning of the region, but also the impacts of the Original Project and Variant C. In *Chapter 3* surface water flows and water quality are considered (in particular, eutrophication), as are the processes of sediment deposition and chemical degradation, all of which affect the physical processes of groundwater recharge and its quality. The evolution of groundwater aquifers is related to the history of river morphology, and the groundwater system (and groundwater resources) of the region are primarily controlled by Danube flows. This chapter also includes an analysis of the physical and chemical properties of the various groundwater systems, including their relationship to ecology, agriculture, and water supply.

Chapter 4 outlines the outstanding significance of the area, with respect to biodiversity and nature conservancy. In these respects the area has significance on a European scale. The aquatic and riparian habitats of the main channel and its numerous side branches, as well as the ecology of the wetland habitats in the floodplain, depend heavily on the discharge, sediment and nutrient regime of the Danube. The anticipated impacts, in addition to changes observed after the diversion of the river in October 1992, are described in *Chapter 4*, with special regard to the effect of the Original Project's peak power operation. Assessments are included of the remedial measures which were considered after the signing of the Treaty in 1977, including weirs in the Danube section alongside the power canal and impoundments of side branch systems as carried out on the Slovak side.

Chapter 5 concentrates on the consequences for agriculture, forestry and fishery. Agriculture is directly affected by any change in soil structure, hence the introductory part of the chapter describes the effects of the altered groundwater regime on sub-irrigation and soil physical and chemical conditions. Interpretation of observed impacts on agriculture is difficult, due to concurrent changes in climatic conditions and agricultural management practices. Nevertheless, attempts are made to quantify losses and the costs that could be resolved to mitigate these effects. Many of the wetland forests are situated on the active part of the floodplain and were exposed to a large drop of groundwater levels after the diversion of the Danube.

Fishery largely depends on the flow and sediment regime of the river and the spawning conditions in the side branches of the Szigetköz. Immediate damage occurred after the diversion of the water into the power canal, but long-term effects due to siltation and changes in physiochemical properties are also anticipated. Considerable detrimental effects on fishery are predicted in the case of peak operation. Due to the dissection of the river by the barrage system the fish fauna is affected in large reaches both upstream and downstream of the Project.

Many effects described both in *Chapter 4* and in *Chapter 5* must be considered as long-term consequences, especially those related to alterations in groundwater quantity, quality and dynamics.

The seismic zoning of the Project has been considered in *Chapter 6*. Since 1965, when the zoning was established, there have been considerable advances in risk assessment and design methods. A review, based on a simple application of current practice, suggests that risk associated with the Project has been underestimated in the past, and that there is potential for the impounding capacity of dykes to be lost in worst-case scenarios. It is concluded that there were substantial grounds for concern over design standards and other unresolved issues when Hungary suspended construction in 1989.

Chapter 7 analyses environmental impact assessment in an international context. Particular attention has been paid to EIA for dams and reservoirs. The data show how aims, scope, processes and procedures, contents and regulations have changed during the last 25 years. This framework provides a context for the evaluation of both the Hungarian and Slovak studies on the G/N project which have been performed during that period.

The abundance of issues and data on the one hand and the lack of knowledge and information in certain fields on the other leaves a great deal of uncertainty over the extent to which the environment will be affected in the short and long term by the Project, and whether or not these changes can be considered acceptable.

CHAPTER 2

RIVER MORPHOLOGY AND RIVER HYDRAULICS
by Klaus Kern

SUMMARY

BED DEGRADATION

River regulation since the 19th century has confined the Danube to a single thread channel but has nevertheless retained a system of active side branches in the Szigetköz and Žitný Ostrov of high value with respect to nature conservancy. Excessive industrial gravel mining since the 1960s together with ford dredging has led to a reduction of low-flow water levels with subsequent lowering of ground-water levels in the vicinity of the channel. Surveys of the riverbed provide evidence that the bed morphology is still governed by accumulation of sediment, and that dredging overwhelms possible impacts of river training and upstream dams.

If riverbed degradation due to reduced sediment supply from upstream were to pose a problem, e.g. near Bratislava, alternative solutions for stabilisation would be feasible as shown at the Upper Rhine and tested at the Austrian Danube.

IMPACTS OF THE G/N PROJECT

(a) Original project

With the construction of the Dunakiliti-Hrušov Reservoir a large part of the Slovak side branch system would be and was actually destroyed. The completion of the Nagymaros Dam would drown almost all islands between Győr and Nagymaros, destroying valuable riparian habitats along their mostly unprotected banks. With a remaining discharge of 50 m³/s in the Old Danube, even with an unspecified possible increase to 200 m³/s during the growing season and with an occasional flood release during a few days only per year, the fluvial habitats of the Old Danube and the adjacent wetlands would be severely endangered. The missing bedload and the impact of peak power operation at Gabčíkovo with daily flow reversal in the lower third of the Old Danube would result in severe bed degradation reaching in some locations up to 3 m after 50 years of operation.

Peak energy production at Gabčíkovo, as it was originally considered, would result in daily water level fluctuations of up to 4.5 m at the upper end of the Nagymaros Reservoir resulting in a devastated strip of land along the banks. The daily change

of flows would also damage the aquatic habitats. Scouring and sediment accumulation could be expected to a certain extent, probably affecting bank filtered water wells in the Nagymaros Reservoir, as well as those downstream of Nagymaros.

(b) Variant C

Almost the same effects can be expected with the operation of Variant C. The prevailing discharge in the Old Danube amounts to about 200-250 m^3/s while flood discharges exceeding 3,000 m^3/s are released in the old riverbed. On such occasions the flow is suddenly released into the Old Danube and the side branches causing above normal degree morphological changes both in the main channel and in the floodplain.

REMEDIAL MEASURES

The impoundment of the remaining flow in the Old Danube with eight "underwater weirs", as was suggested, would prevent the degradation of the riverbed, but not necessarily sustain groundwater to the desired level, as is shown by German experience at the Upper Rhine barrage of Rhinau. In addition, the "underwater weirs" would create a sequence of small reservoirs with the well known detrimental effects on the aquatic habitats due to siltation, reduced flow velocities, etc.

FLOOD PROTECTION

As far as flood protection is concerned there was and is no need for the G/N Project. The Szigetköz problems were solved by reinforcement of the dyke systems in the 1960s and 1970s, providing a 100-year flood protection which complies with international standards. Downstream of Győr some works have to be completed to reach the same level of security. In this reach the Slovak levees were raised to a higher level according to the Original Project plans *after* Hungary had suspended works at Nagymaros.

The incomplete state of construction of Variant C called "Phase I" falls below the mutually agreed safety standards of the Original Project. Neither the 100-year flood nor the 1,000-year flood can be discharged by the structures at the same level of safety which was previously adopted. Immediately after closure of the Danube, the Čunovo weir could not even safely handle the flood discharge for which it was designed. The high November flood in 1992 (which was still less than half of the 100-year design flood to be released at Čunovo at Phase I) caused considerable damage in the downstream channel, on the floodplain, in the side arms and at the structure itself. The danger of uncontrolled flood – possibly overtopping the reservoir dyke –imposes an additional flooding risk on Hungary.

In the past many floods in this region were caused by so-called ice jams, i.e., a barrier of accumulated ice floes blocking the channel. Due to river regulation the danger of ice floods was considerably reduced. With the construction of a large reservoir – only necessary for peak energy production – a solid ice cover is likely to develop every winter increasing the risk of ice jams at its upper end or at the weir gates. The safe release of broken ice is possibly the most difficult task in reservoir operation. Therefore certain operational procedures were established in the Original Project. The state of construction of Variant C, Phase I, does not allow the same procedures of ice release, as was indicated by ice problems in January 1993; a significantly higher risk of uncontrolled flood discharge was accepted by the Slovak side.

NAVIGATION

Plans for river training to facilitate navigation were worked out in the 1960s, but were only partially fulfilled due to the anticipated installation of the G/N System. In the Danube stretch in the region of the power canal, where the regulation was completed, only minor problems concerning a sharp bend remain, not presenting significant restrictions to navigation. Between Sap and Gönyü additional fords appeared after the opening of the power canal. Recent preliminary investigations by VITUKI and a Dutch-Hungarian consortium indicate that traditional regulation methods including some maintenance would be sufficient to meet the requirements established by the Danube Commission. It is quite common for there to be permanent dredging in international fairways, as is shown on the Rhine.

2.1 THE NATURAL SYSTEM

Downstream of the fault gap through the Alps-Carpathians at Bratislava the Danube flows through the Little Danube Plain, where the majority of its sediment deposits. Together with the river Váh the Danube has eventually formed a long alluvial cone, stretching from Bratislava to Komárom. At its upper edge the Danube separates into three branches forming an inland delta which is unique for European river systems. Period maps show that the river repeatedly switched its main course since Roman times.

In the middle of the 19th century the main channel was flowing south forming an anabranched meandering river. Continuous aggradation was prevailing, and the river was forced to erode new branches with each major flood depositing large amounts of sediment in its previous bed. Thus a confusing system of more or less flushing side branches existed at that time, embracing numerous islands. The prevailing accumulation of alpine sediment resulted in a peculiar morphology: the main channel and its adjacent side branch system are situated at a higher altitude than the extended floodplain. Its large capacity for infiltration into the groundwater – even at low flow – is an essential consequence of this phenomenon.

The ever changing system of side branches with the deposition, scouring and transportation of sediment accompanied by a frequently inundated floodplain, is responsible for the very great diversity of habitats that existed and still exist in this river section. Scoured reaches of great depth, shallow fords, dissected river arms, etc., are adjacent habitats. *The fluctuation of discharges and water levels was and still is a vital prerequisite for the existence of all types of habitats in the wetlands in this Danube section.*

2.2 HISTORICAL DEVELOPMENT

2.2.1 RIVER REGULATION

Large scale river regulation started in the middle of the 19th century with the construction of floodplain levees confining the inundated area to a width of about 2-6 kilometres in the reach between Bratislava and Gönyü. Between 1886 and 1914 a mean-flow channel of 300-380 m width was created for flood protection, especially related to ice problems, and for the improvement of navigation. The meandering of the low flow within the then created channel was intolerable for navigation and required a low-flow regulation by fixing the thalweg with spur-dykes (groynes), eventually resulting in a navigation channel of 80-120 m width and 2 m depth (Stančík *et al.,* 1988).

Although the river regulation carried out at the Danube between Bratislava and Gönyü was similar to the Upper Rhine training, *aggradation* was still prevailing instead of incision. Measured rates of aggradation between rkm 1800 and rkm 1841 amounted to 2.4-2.7 cm annually before excessive gravel exploitation was started (Bačik *et al.,* 1992).

Until the 1960s, many of the side branches were still open and the discharge in the branch system in the reach near Gabčíkovo (rkm 1833-1816) amounted to about 20% for a total discharge of 1,005 m^3/s measured at Bratislava (data from the year 1961). At a discharge of 1958 m^3/s, which is exceeded on 168 days of the year, the side branches carried up to 500 m^3/s (data from 1960) (Mucha, 1993). *Thus it can be stated, that until the 1960s the side branch system and the active floodplain were fully integrated in the fluctuations of discharge and water levels which are vital to the wetland ecosystem.*

2.2.2 RIVERBED DEGRADATION

From an engineering point of view there should be an equilibrium between the amount of sediment entering a certain river section and leaving it at its down-stream end, in order to maintain a constant bed and water level. Since river training works, including the construction of groynes, did not succeed in balancing

sediment transport capacity and sediment load, continuous dredging of fords was indispensable for navigation. In addition, growing amounts of gravel have been extracted from the entire river reach between Bratislava and Budapest for industrial purposes.

Downstream of Sap/Palkovičovo (rkm 1810) the gradient of the river drops from 0.35 to 0.17‰, at the mouth of Mosoni Duna (rkm 1793) to 0.10‰ and at Komárno (rkm 1768) to only 0.07‰ (Stančík et al., 1988). In this reach excessive dredging was carried out by both countries (*Figure 2.1*).

Table 2.1 gives dredging data of different Danube reaches in Hungary covering different time spans. No specific information about dredging in the Slovak Danube stretch between rkm 1880 and rkm 1850 is available to the authors. But the total dredging volumes of the reach Rajka-Gönyü indicate that considerable dredging was carried out in the 1960s and the early 1970s (*Table 2.1, Figure 2.1*). Half of the dredging was done for the removal of fords to facilitate navigation. Since the 1960s large scale industrial dredging was carried out in the Szigetköz reach amounting to average excavated gravel volumes of more than 700,000 m^3 per year. In some years dredging in this river stretch exceeded 1 million m^3 with a maximum value of 1.526 million m^3 in 1989 (VITUKI 1993b). Dredging of fords was necessary at all times independently of the arriving bedload, because the fluvial rearrangement of sediment in the riverbed was unfavourable to navigational requirements.

The exploitation of gravel was not shared equally on all river reaches; the stretch between Gönyü and Komárom was almost exclusively exploited by Slovakia while the lower common Danube reach was intensively excavated by both countries. In both reaches navigational dredging was insignificant.

Table 2.1*: Gravel dredging in different reaches and periods along the Danube (mio=million) (Kern, 1994a).*

Reach	rkm 1849 to rkm 1791 (Rajka - Gönyü)	rkm 1850 to rkm 1790 (Rajka - Gönyü)	rkm 1849 to rkm 1791 (Rajka - Gönyü)	rkm 1791 to rkm 1664 (Gönyü - Komárom)	rkm 1766 to rkm 1708 (Komárom Ipoly-mouth)	rkm 1694 to rkm 1659 (main branch)
Period	1949 - 66	1963 - 79	1969 - 91	1965 - 91	1970 - 88	1970 - 79
Total gravel volume (m³)	no data	12.9 mio	16.4 mio	20.7 mio	27.5 mio	16.1 mio
Ford dredging & river training (m³)	⁄ 6.4 mio	ca. 7 mio	8.9 mio	372,000	200,000	no data
National dredging (industr.)	no data	ca. 6 mio				no data
–Slov. (m³)			4.8 mio	19.8 mio	9.0 mio	
–Hung. (m³)			2.7 mio	535,000	18.5 mio	
Annual dredging (m³/yr)	350,000 (only navi-gational)	760,000	715,000	768,000	1.447 mio	1,610,000
Specific annual dredging (m³/rkm•yr)	6,000 (only navi-gational)	12,600	12,300	28,000	25,000	46,000

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Rajka - Gönyü
(rkm 1850-1791)

*)no data on ford dredging
**)no data on national dredging
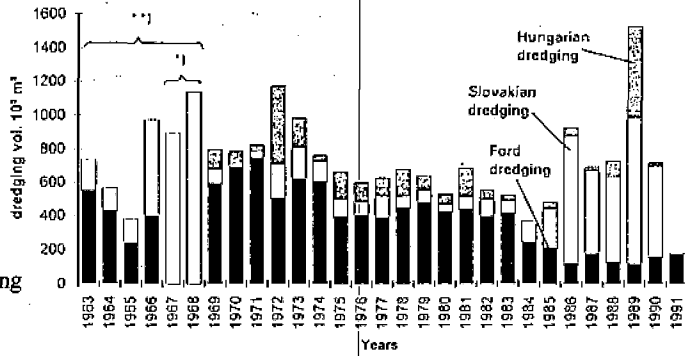
Gönyü - Komárom

(rkm 1790-1764)
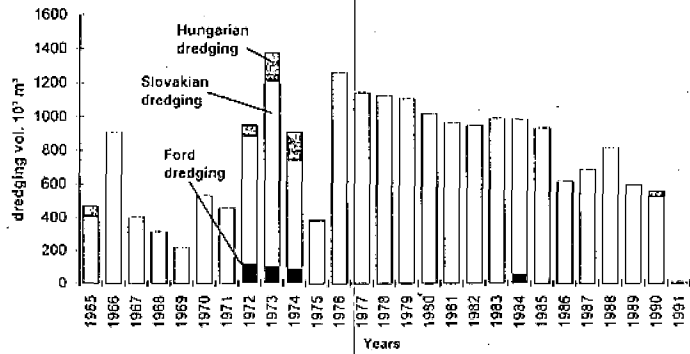
Komárom - Ipoly

(rkm 1766-1708)
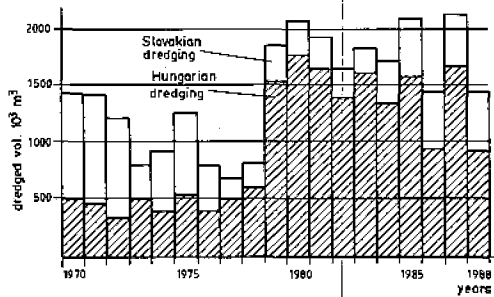
Figure 2.1: Volumes of dredged sediment from the Danube between Rajka and Ipoly mouth (Kern, 1994a)

Between Nagymaros and Budapest excessive dredging was carried out for industrial purposes until 1980 when it was stopped because of negative impacts on the bank-filtered well system of the Budapest waterworks and on navigation. After 1979 only minor dredging of fords was done. On the 32 km-reach of the Szentendre Duna 4.0 million m^3 of gravel was excavated between 1970 and 1980 and about 100,000 m^3 in 1987 (Laczay, 1988).

The bedload transport capacity drops along the river with the reduction in slope. Before the construction of dams in Austria the arriving bedload at Bratislava was estimated to 600,000 m^3 per year, in the Szigetköz to about 100,000 m^3, around Komárom to about 50,000 m^3 and at Nagymaros to only 10,000 m^3 per year. *Comparing these figures to the annually dredged volumes of gravel (Table 2.1, second line from the bottom) it is obvious that all Danube reaches were heavily overdredged, especially when considering reduced levels of bedload arriving at Bratislava after dam construction in Austria.*
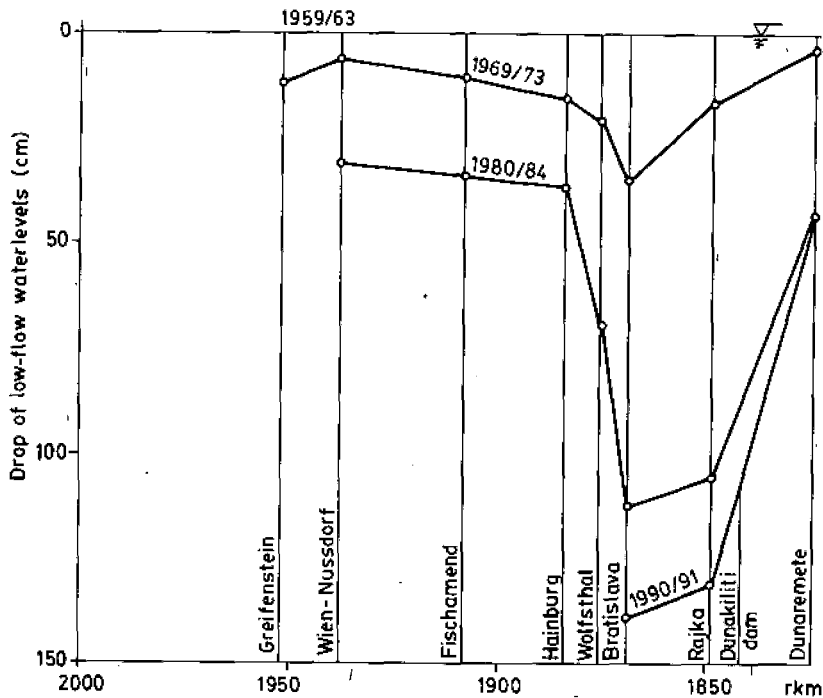
Figure 2.2: *Drop of low-flow water levels (1,000 m³/s) since 1959/63 in the Danube between Vienna and Dunaremete (VITUKI, 1993d)*

The excessive channel dredging beyond the indispensable need of navigation maintenance has led to a severe disturbance of river morphology affecting the entire river ecosystem. Between Nagybajcs (rkm 1802) and Gönyü (rkm 1791) the low flow water levels dropped by more than 1.50 m (*Figure 2.3*). *Figure 2.2* shows the drop of low-flow water levels between Hainburg/Austria and Dunaremete (rkm 1826) with its maximum between Bratislava and Rajka. Obviously riverbed degradation increased significantly entering the Slovak reach at rkm 1880.
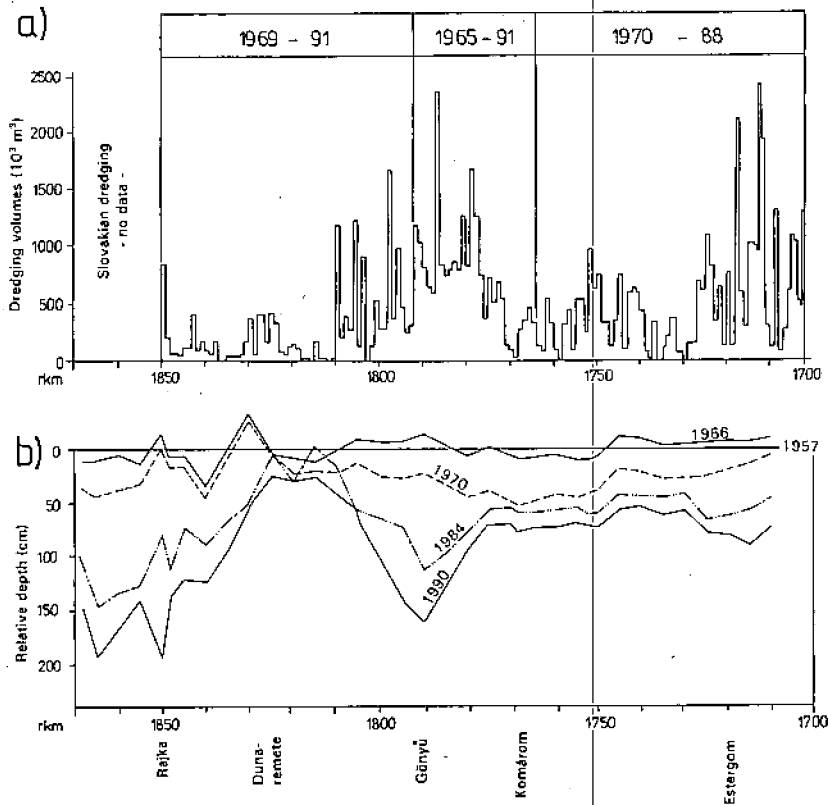
Figure 2.3: a) *Dredged volumes of sediment in the Danube along the Slovak-Hungarian border at different periods of time. b) Lowering of the low-flow water levels (ca. 1,000 m^3/s) since 1957 (Kern, 1994a)*

The lower part of *Figure 2.3* shows the drop of the navigational low-flow water levels. The horizontal line represents the 1957 navigational low-flow water level. The water levels of 1966 reveal that the riverbed remained rather stable until the

mid 1960s. Between 1966 and 1970 a considerable drop was registered between Bratislava and Rajka and especially downstream of Dunamerete. Dramatic changes occurred in the period after 1970. Apparently the drop of water levels was not uniform; former aggrading or rather stable sections degraded severely, e.g. upstream of Rajka and in the vicinity of Gönyü. Comparing the lowering of the water levels and the amount of dredging a close relationship is obvious.

Both graphs reveal a considerable drop of low-flow water levels in the vicinity and downstream of Bratislava after 1966. An analysis of the gauge data of Bratislava also shows that the erosion process did not start before the middle of the 1960s (Kern, 1994a).

Figure 2.4 shows the change of the riverbed, the average depth of dredging and the drop of low water levels between Rajka and Gönyü in the time period between 1969 and 1991. The horizontal reference line ("0"-line) in this graph represents the riverbed and the low-flow water level, respectively, in the year 1969. Accounting for natural aggradation tendencies, the morphological behaviour of the river generally shows a distinct relationship between dredging activities and lowering of the riverbed. Between rkm 1850 and rkm 1840 the lowering of the riverbed corresponds to the amount of dredging. The lack of dredging in rkm 1835/36 resulted in local aggradation clearly indicating that the river would fill up its bed in the Szigetköz reach without dredging even with the operation of upstream dams. The low water levels are obviously governed by dredging and prevailing accumulation of sediment in this Danube reach. The drop of the low-flow water levels at the upper and lower end of the reach are caused by dredging surpassing accumulation of sediment, while in the centre of the reach aggradation is still prevailing and leads to an almost stable water level.

The morphology of the river is governed by the accumulation of sediment and the excavation of gravel. Overdredging in many reaches resulted in a significant drop of water levels. In some reaches (e.g. around Palkovičovo) aggradation is overruling excessive dredging. There is no indication that the reduced level of sediment supply from Austria has significantly influenced the river morphology downstream of Rajka. Without dredging the Szigetköz reach of the Danube could be expected to accumulate sediment even today. Due to the lack of data no certain conclusion can be made for the Slovak reach. But the sudden drop of water levels at Bratislava after the year 1967 indicate excessive (industrial) gravel dredging rather than the influence of upstream dams.
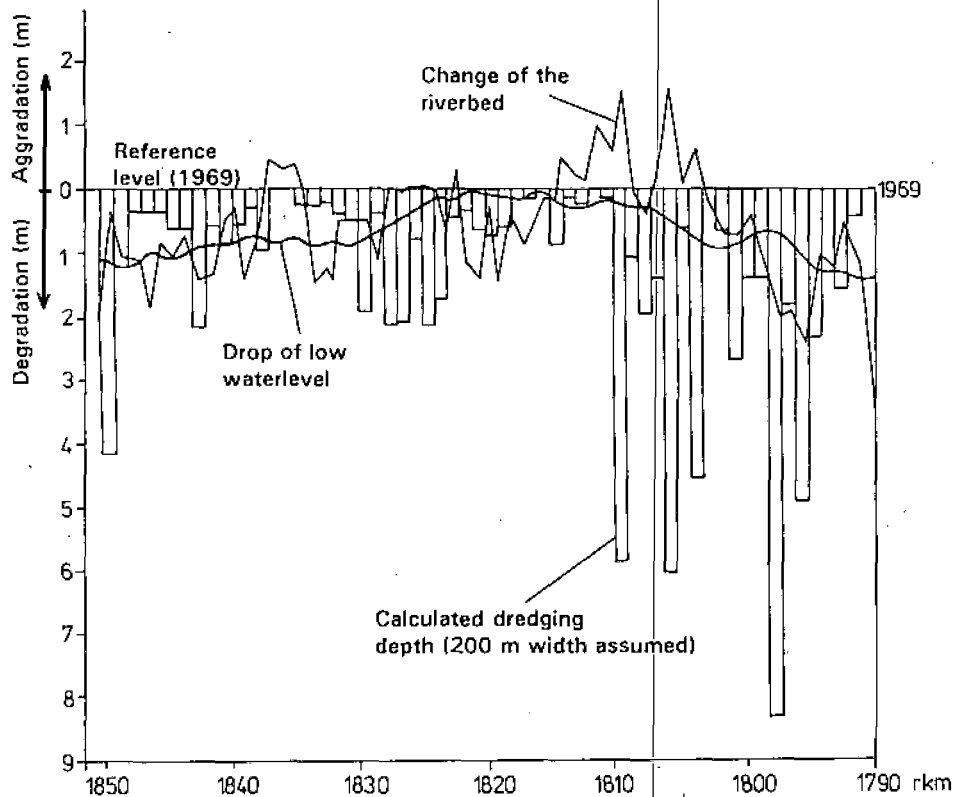
Figure 2.4: *Relative changes of the riverbed, drop of low-flow water levels and average depth of dredging between 1969 and 1991 in the Danube between Rajka (rkm 1850) and Gönyü (rkm 1791) (after VITUKI, 1993b; see also Plate 2.1).*

This contrasts with the situation on the Upper Rhine, where early regulation works caused severe incision of the riverbed, and where the missing bedload downstream of the last barrage of Iffezheim would lead to bed degradation without the continuous addition of sediment by man (Kern, 1994b).

Before the degradation of the bed started in 1967/68, about 20% of the side branch system in the Szigetköz was permanently supplied with water even at low flow conditions. After degradation the threshold for the branch system inflow increased to 2,500-2,700 m³/s which occurs for 75-100 days of the year. In addition, entrance sections of side branches were closed in the last 30 years in order to maintain minimum water depths required for navigation.

It can be assumed that the over-excavation of gravel has been done on the expectation of the construction of the Gabčíkovo-Nagymaros Barrage System, at least in certain river reaches like in the Dunakiliti/Čunovo Reservoir, where the rise of water levels has compensated for the drop around Bratislava. In this regard riverbed degradation is closely related to the project plans.

2.2.3 NAVIGATION

(based on Laczay, 1994a)

All river training activities in the Szigetköz reach of the Danube including the low-flow regulation until 1940 did not result in a permanent and sufficient fairway for international shipping. In 1963, the Hungarian-Czechoslovak Joint Engineering Committee outlined and approved principles for further improvement of the navigation channel by traditional methods, i.e., closure of side arms and rearranging banklines to convey up to 3,000 m^3/s in the main channel, confining the channel in width to increase sediment transport capacity. A general river training plan was prepared for the stretch from rkm 1842-1816 only, because all other reaches would be affected by planned impoundments of the G/N Project. The construction was performed in the 1960s and 1970s. Additional work of minor extent was done upstream of Dunakiliti and downstream of Ásványráró.

It was confirmed in the late 1970s that, until the G/N Project comes into operation, no further comprehensive river training activities were justified. Navigation was to be maintained by occasional dredging.

The most severe navigational obstacle in the last years before the closure of the Danube was caused by the excavation of the inlet and outlet canal of the Dunakiliti weir. Middle bars developed in the overwidened main channel decreasing navigational low flow depth to 1.6 m around Dunakiliti.

An old navigational problem is the sharp bend at Bagomer (rkm 1814). No river training solution is available to solve the problem, but vessels can negotiate it, since there are no depth restrictions here. No other main obstacles for navigation are known in this reach, so the bypass canal only solves these two problems, one of which was caused by the project itself.

Between Sap and Gönyü sedimentation prevails, and some locations are restricted in width and depth. Additional shallow sections have developed since the opening of the power canal in the stretch between rkm 1808-1800.

2.2.4 FLOOD PROTECTION

(based on Laczay, 1994b)

The first continuous dyke system was built after the 1883 flood. The levees were damaged by the 1887 and 1899 floods, the reconstruction was finished in 1906 with a crest level of 1 m above the 1899 flood level. In 1954, a large flood caused four levee breaks along the Danube (see *Plate 2.2*). Two thirds of the Szigetköz area was inundated causing damage of 383 million HUF (in paragraph 1.31 of the Slovak Memorial the damage were seriously overestimated at 1.5 billion U.S.$).

After the 1954 flood, improvement of the dyke system was planned on a statistical basis fixing the 100-year flood levels as a design standard. Reconstruction of the levees according to the new standard was performed in 1955-1961. Revisions of the design flood levels due to morphological changes of the channel and the floodplain were carried out in 1957, 1964 and 1976. All design levels were agreed in the Danube Subcommittee of the Hungarian/Czech/Slovak Border Water Committee and approved by the Plenipotentiaries.

Owing to the reinforced dyke system, the historical flood of 1965 caused no major failure in the Szigetköz reach of the Danube. The entire damage on the Hungarian side between Rajka and Nagymaros amounted to about 1,000 million HUF and not to 1,500 million HUF as stated in paragraph 1.33 of the Slovak Memorial.

In 1965, 94% of the levees did not meet the safety requirements of the 100-year flood. Reinforcement of the dyke system in the Szigetköz reach was finished in 1977 incorporating a freeboard allowance of 1.2 m above the 100-year flood levels. Sufficient cross dimensions and the necessary structures to prevent seepage had been built. The exception was along the stretch Rajka-Dunakiliti, where the Dunakiliti-Hrušov Reservoir dyke was planned. On the left bank of the Mosoni Danube the flood protection system also did not meet the requirements in 1977.

Between Győr and Nagymaros only 18 km of Danube banks need flood protection on the Hungarian side because of the altitude of the adjacent area. The flood protection system consists of dykes, walls, elevated public roads and a railway line. Despite repeated reinforcements only a short length of the levees met the design requirements in 1977, e.g. the elevation of the railway line equalled the 100-year flood level without freeboard allowance.

Conclusion. By 1977, the major part of the Hungarian flood protection system met the safety level on which both sides had agreed, i.e., 100-year design flood plus 1.2 m freeboard allowance and sufficient cross dimensions of levees with seepage control.

2.3 IMPACTS OF THE ORIGINAL PROJECT

2.3.1 CONSTRUCTION

Dunakiliti-Hrušov Reservoir

The construction of the Dunakiliti-Hrušov Reservoir would destroy and actually has destroyed about one third of the Žitný Ostrov floodplain. Through the impoundment of 200 million m^3 of water the previous river ecosystem characterised by numerous islands, side branches and wetlands would have been lost. The

average flow velocity of the former river would have been reduced from 2.0 m/s to about 0.3 m/s. The water level at Bratislava has actually risen by 1-2 m since the closure of the Danube, reaching its original level before degradation of the bed.

Old Danube

Dredging between rkm 1811 and rkm 1817 should level out the step created by the deepening of the tailwater canal of Gabčíkovo.

Nagymaros Reservoir

The Nagymaros Reservoir would have extended from the Gabčíkovo power station (rkm 1811+8) to Nagymaros (rkm 1696). Its backwater would reach up to rkm 1823 in the Old Danube, more than 20 km upstream of the Malý Dunaj (= Váh) mouth and several kilometres upstream of the confluence of the rivers Hron and Ipoly. According to the Joint Contractual Plan, channel dredging should lower the water level at a discharge of 2,300 m^3/s from Ásványráró (rkm 1816) to Gönyü (rkm 1791) by 2.00 m at Palkovičovo (rkm 1811), by 1.10 m at Medvedov (rkm 1806), and by 0.70 m at Nagybajcs (rkm 1802). The construction of the barrage would cause the inundation of about two dozen islands situated between Gönyü (rkm 1791) and Nagymaros. Most of the riparian zones of these islands rendering valuable ecotones were left unprotected and carry softwood vegetation. In addition, established riparian zones of 300-350 km length of several tributaries and of the Danube itself would be inundated. The flow velocities (without peaking mode) would be considerably smaller than before, thus the aquatic habitats would substantially alter their physical properties.

Downstream section of Nagymaros

According to the Original Project channel dredging along Szentendre island from Nagymaros to rkm 1656 should lower the low-flow water levels by 0.60-1.20 m in order to increase the head of the power plant. Dredging, which was carried out mainly for industrial purposes, was stopped in 1980 because of problems with the bank filtered wells of the waterworks of the city of Budapest.

2.3.2 OPERATION

Dunakiliti-Hrušov Reservoir

Depending on the actual flow into the reservoir, certain peaking modes were established as operation rules for Gabčíkovo. *Figure 2.5a* shows the fluctuations in

the Dunakiliti-Hrušov Reservoir resulting from mode 1500/700, which means 1,500m³/s inflow produce 700 MW. In this case there would be two daily peaks in the reservoir water level with fluctuations of about one metre. The backwater reach was expected to vary between rkm 1858/60 and rkm 1870/72. 90% of the bedload was expected to deposit at this place and should be dredged continuously; 77% of the suspended load was expected to deposit, hence the reservoir's life time was calculated to be about 60 years.

Old Danube

The discharge regime of the Danube between Dunakiliti (rkm 1842) and Palkovičovo (rkm 1811) would be completely changed with the implementation of the Original Project (and was changed in fact with the operation of Variant C; see *Chapter 2.4*).

Table 2.2 shows the main hydrological and morphological impacts that could be anticipated in the Old Danube with the implementation of the Original Project. During 350 days of the year, 50-200 m³/s would be released from the reservoir – 200 m³/s only in case of the need for vegetation. Any water level fluctuations would be limited to 12 days of the year on average, when the inflow into the reservoir exceeds 4,000 m³/s. Such an artificial discharge regime generates a low-flow bed suitable for the prevailing discharge of 50(-200) m³/s with a characteristic pattern of fluvial habitats. Once a year or every other year a larger flood would destroy nearly all fluvial and riparian habitats that had developed and the cycle of restructuring would start again. Regular maintenance would be required to ensure the flood discharge capacity of the channel, but this would have similar destructive effects as the larger floods themselves in disrupting the fluvial habitats.

According to the Joint Contractual Plan the low-flow water level – that had been lowered since 1967/68 through excessive channel dredging – would drop by 2.50-3.00 m below the regulation water level. Flow velocities would be reduced to less than one metre per second (CEC, 1993b). In times of high discharges (but still less than 4,000 m³/s) and during daily peak energy production with a release of 4,000-5,200 m³/s at Gabčíkovo (*Figure 2.5*) there would be a backwater reach up to rkm 1823 in the Old Danube.
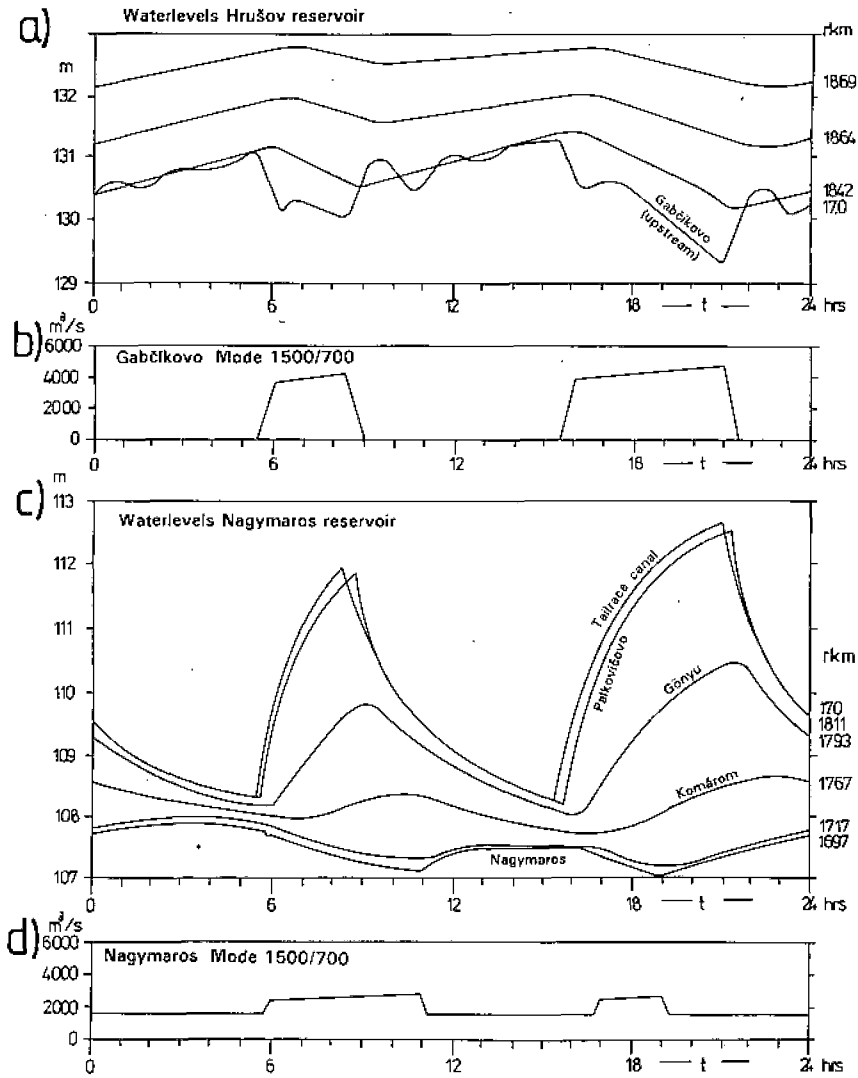
Figure 2.5: Peak operation and daily water level fluctuations (mode 1500/700): **a)** Daily water level fluctuations at different cross-sections of the headrace canal and the Dunakiliti-Hrušov Reservoir **b)** Discharge release at Gabčíkovo **c)** Daily water level fluctuations at different cross-sections of the tailrace canal and the Nagymaros Reservoir **d)** Discharge release at Nagymaros

Table 2.2: Hydro-morphological impacts of the Original Project on the Old Danube

OLD DANUBE			
	short term (5-10 yrs.)	**medium term (10-20 yrs.)**	**long term (20-50 yrs.)**
Discharges	• 50/200 m³/s should be released from the reservoir into the Old Danube higher releases only at discharges exceeding 4,000 m³/s (ca. 12 d/yr.) • daily flow reversal for a few kilometres upstream of the conjunction with the power canal caused by peaking operation		
Water levels	• sudden drop of water levels by several metres	• gradual lowering of the water levels in eroding reaches (see below)	
Flow velocities	• reduction of flow velocities from 1.2-2.0 m/s to less than 1.0 m/s at 50 m³/s; • reduced flow velocities in the backwater reach of the power canal conjunction		• minor variations of flow velocities with changes of bed morphology
Fluctuations of discharges & water levels	• exclusion of all discharge and water level fluctuations for ca. 350 d/yr. except for the reach influenced by backwater where daily fluctuations of 4 metres would occur (*Figure 2.5*) • sudden rise and fall of discharges and flow velocities in case of flood discharge release		
Riverbed stability	• during a flow of 50/200 m³/s, the Danube channel would eventually form an adequate low-flow bed • high floods in the first years would yield first riverbed deformations	• after 20 yrs. operation significant scouring was predicted with riverbed degradation up to 1.5 m caused by total retention of bedload in the Dunakiliti-Hrušov Reservoir (Bačik et al., 1992)	• after 50 yrs. operation scouring was predicted to reach 3 m in some sections leading to a severe drop of the prevailing water levels at 50/200 m³/s (*Figure 2.6*) (Bačik et al., 1992)
Riverbed structures	• gradual formation of a low-flow bed; silting up of reaches with smaller velocities • spreading of vegetation in the channel outside the low-flow bed	• total destruction of the low-flow bed structures at higher flood discharges or by maintenance with partial erosion of silted reaches • growth of woody vegetation on higher elevations in the channel presumedly causing a narrowing of the discharge cross-section (with the threat of further bed erosion), if not removed by regular maintenance	
Riparian structures (ecotones)	• following the drop of the water level of several metres the banks of the old channel would become unstable and collapse partially and locally	• the formation of the low-flow bed would create a new riparian zone which would periodically be destroyed at higher flood discharges; thus the riparian habitats would suffer from instability caused by an unnatural difference between average and flood discharges	

The sharp rise of discharges at the begin of peak energy production would result in a rise of water levels at the sill of Palkovičovo (rkm 1811) of about 4 metres

depending on the peaking mode (*Figure 2.5*; refer also to Karadi and Nagy, 1993). In this case the flow direction would reverse and the water would flow upstream to the end of the backwater one or two times daily. Thus there would be two different sections in the Old Danube: an upper part from Dunakiliti barrage to Lipót (rkm 1823) with no water level fluctuations at all except for a few days per year, and a lower part with large fluctuations every day damaging fluvial and riparian habitats.
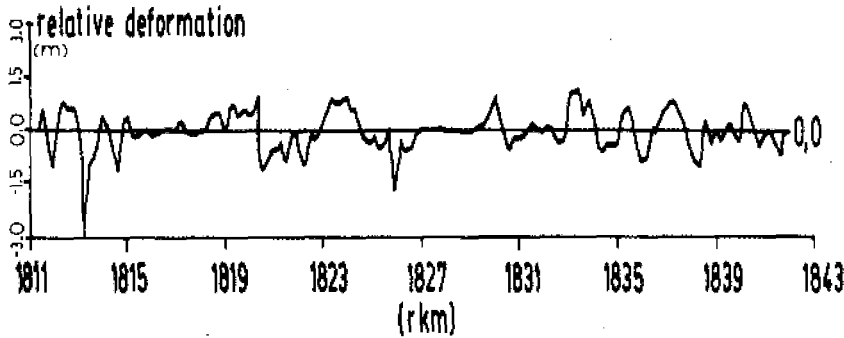
Figure 2.6: *Anticipated relative change of the riverbed after 50 years of operation (after Kališ and Bačik, 1992)*

Since all bedload will be trapped in the Hrušov Reservoir, eventual degradation of the bed should be expected even with few flood discharges per year. Kališ and Bačik (1992) predicted up to 3 m scouring in some sections after 50 years of operation entailing a further drop of the prevailing 50/200 m³/s water levels. *Figure 2.6* shows the deformation of the riverbed simulated for a 50-year period of operation.

Altogether fluvial and riparian habitats would either be destroyed or would suffer from instability caused by the imposed discharge regime. Large daily water level fluctuations in the lower part of the Old Danube contrast a rather steady water level regime in the upper part of the reach. The degradation of the riverbed previously caused by excessive upstream channel dredging would continue due to the total retention of the bedload at the Dunakiliti barrage.

The Szigetköz floodplain

Table 2.3 indicates the major hydrological impacts of the original project that could be anticipated on the Szigetköz floodplain. The discharges that would be released in the side branch systems on both sides of the Old Danube could by no means compensate for the drop of groundwater-tables or for the loss of frequent flushing and inundation that occurred before the 1960s.

Due to the distribution of flows between the power canal and the Old Danube, natural flow into the side branches and the floodplain would occur only at discharges much greater than 4,000 m³/s. There would be flow in some side branches at 6,500-7,500 m³/s and in almost all during inundation of the floodplain at 7,500 and 8,500 m³/s corresponding to a 5- to 10-year flood and a 10- to 25-year flood, respectively (CEC, 1992).

Table 2.3: Hydrological impacts of the Original Project on the Szigetköz floodplain

SZIGETKÖZ FLOODPLAIN		
	short term (5-10 yrs.)	medium term (10-20 yrs.)	long term (20-50 yrs.)
Discharges	● constant supply for side branch systems: 15/25 m³/s on the Hungarian side ● flow in some side branches from Old Danube every 5-10 yrs ● flow in almost all side branches every 10-25 yrs. with complete inundation of floodplain		
Groundwater-table	● in the vicinity of the Old Danube drop of the groundwater-table to the prevailing flow level of 50 m³/s ● insufficient recharge of the groundwater by the side-arm system ● gradual decline of groundwater-table towards the Danube	● clogging of most side branch reaches could be expected because regular supply discharges would not be able to prevent sedimentation of fines in large areas ● effective flushing would occur only every 10-20 yrs. with higher flood discharges	● eventual scouring of the Old Danube riverbed would cause further drop of the groundwater-table
Fluctuations of the groundwater-table	● exclusion of all groundwater-table fluctuations for ca. 350 d/yr. ● the duration of the flood discharges in the side branches will be too short to result in significant fluctuations of the groundwater-table		
Floodplain morphology	● until 1967/68 flushing of side arms with scouring, deposition and lateral movement occurred several times a year which would be hence limited to rare flood events ● deposition of at least two thirds of the incoming suspended sediment load in the Dunakiliti-Hrušov Reservoir would considerably reduce the sediment input into the floodplain		
Floodplain habitats	●desiccation of almost all wetlands in the floodplain within a few years except for narrow riparian strips along those side arms that are supplied with constant discharge; stagnancy of the evolution of all habitats due to missing dynamics of waterflow and sediment input		

Table 2.4: Hydro-morphological impacts of the Original Project on the Nagymaros Reservoir

NAGYMAROS RESERVOIR		
	short term (5-10 yrs.)	**medium term (10-20 yrs.)**	**long term (20-50 yrs.)**
Discharges	• daily fluctuations from 1,000 m³/s to more than 5,000 m³/s depending on the mode of peak operation (*Figures 2.5*) • with mode 900/700 no release of water at Gabčíkovo for 18.5 hrs.		
Water levels	• at 2,300 m³/s compared to pre-dam conditions (without peaking): +6 m at Nagymaros, ±0 at Vének, -2 m at Palkovičovo (dredging)		
Flow velocities	• v_{min}/v_{max} flow velocities through peak operation (mode 2000/700): 0.00/0.95 m/s at tailwater Gabčíkovo (rkm 1819.45), 0.02/1.94 m/s at Palkovičovo (rkm 1811.05), 0.28/1.59 m/s at the mouth of Mosoni Danube (rkm 1793.3), 0.32/1.19 m/s at Komárno (rkm 1768.3) (Karadi and Nagy, 1993)		
Fluctuations of discharges & water levels	• about 4,000 m³/s daily fluctuations of discharges • daily water level fluctuations through peak operation (mode 2000/700): 4.64 m at tailwater Gabčíkovo (rkm 1819.45), 4.38 m at Palkovičovo (rkm 1801.05), 2.65 m at the mouth of Mosoni Danube (rkm 1793.3), 1.06 m at Komárno (rkm 1768.3) (Karadi and Nagy, 1993)		
Riverbed stability	• rather high flow velocity fluctuations with peak operation would cause general scouring in the entire reach except for the last 20 km upstream of Nagymaros (Bognár and Rákóczi, 1988)	• according to (Bognár and Rákóczi, 1988) eventual "armouring" of the riverbed would be expected by selective transport of smaller grain sizes leaving a protective layer of coarser gravel on the bottom of the riverbed; therefore scouring was expected to cease after 0.1-0.2 m depth	
Riverbed structures	• all islands between Gönyü (rkm 1791) and Nagymaros would be lost with the rise of the water level • all other aquatic habitats would experience thorough changes in current, deposition and scouring • many riverbed structures were already destroyed by channel dredging	• bank stability would be highly endangered by the sharp rise and fall of water levels requiring rip-rap protection with filter layers • eventually new riverbed structures would evolve according to the governing hydraulic regime caused by peak operation; nevertheless the hence prevailing conditions would be unfavourable to all aquatic habitats; the daily fluctuations between low-flow conditions and high flood flows – naturally occurring on less than 5 d/yr. – impose instability on all riverine habitats and must be regarded as a major detrimental impact of peak operation;	
Riparian structures (ecotones)	• with the permanent inundation of numerous large islands, valuable ecotones would be lost and all riparian structures between Gönyü and Nagymaros would be inundated as well	• daily water level fluctuations up to 4.38 m at Palkovičovo (rkm 1811) and 1.06 m at Komárno (rkm 1768) would produce a devastated strip of land of several metres width (about 3-12 m at slopes of 1:3); no vegetation growth would be possible in this zone; • the riparian habitats that are highly valuable in large rivers would not exist any more	

Water level fluctuations influencing groundwater recharge and quality would be limited to an average of 10-12 days per year but not necessarily in a consecutive row. Thus the significant contribution to groundwater recharge by rare but long lasting floods would not longer occur.

Floodplain habitats depending on the height and fluctuation of the groundwater-table as well as on the frequency, height and duration of inundations would be governed by the prevailing low-flow and low groundwater table conditions. The desiccation of the Szigetköz floodplain would eventually alter the previous riverine wetlands into dry habitats similar to large floodplain areas of the Upper Rhine near Breisach. In the case of impounding the side branch system with artificial supply a completely different wetland ecosystem would develop adapted to nearly stagnant surface and groundwater levels.

Nagymaros Reservoir

Several peaking modes were envisaged in the Original Project. Depending on the average flow, certain peaking modes were considered as operation rules for the Gabčíkovo power plant. For instance, at mode 900/700, there would be no release at Gabčíkovo for 18.5 hours per day (Nagymaros would still release 1,000 m^3/s using its reservoir capacity and discharges from tributaries). Within half an hour the discharge would rise to 3,630 m^3/s with an acceleration of 120 m^3/s per minute. Within 4.5 hours the maximum discharge up to 5,110 m^3/s would be released followed by a sharp descent to 0 within half an hour at a rate of 170 m^3/s per minute (Karadi and Nagy, 1983). Higher discharges would allow for the release of two peaks per day. *Figure 2.5* shows daily water level fluctuations in the Dunakiliti-Hrušov Reservoir (a) and the Nagymaros Reservoir (c). The operation rules for the Gabčíkovo and Nagymaros power plant are given in (b) and (d), respectively. The daily fluctuations of discharges, flow velocities and water levels as documented in *Table 2.4* are detrimental to the whole ecosystem in many respects: The riverbed would be endangered by erosion in certain reaches as was concluded by Bognár and Rákóczi (1988). This process would only be stopped in case of eventual armouring. Near the banks and in the vicinity of the Nagymaros barrage accumulation of fine sediment can be expected.

The ever changing flow conditions and water levels are very unfavourable to all aquatic and riparian habitats. The most valuable habitats of large rivers are located in the riparian zone at the transition from water to land. The riparian zone exposed to the daily water level fluctuations would stay without vegetation and lose its high ranking ecological value. The former valuable wetland vegetation of the islands would be impounded anyway.

The aquatic habitats would also suffer from the ever changing flow conditions. The substrates would never be stable; suspended sediment would settle in the "low flow" periods of the peaking mode and would be flushed away during the "flood

flow". The aquatic fauna would be significantly reduced in diversity and abundance, even compared to reservoir conditions without peaking operation (see *Chapter 4.4.2.4*).

Altogether the construction and operation of the Nagymaros Barrage would destroy valuable habitats and generate very unfavourable living conditions for the aquatic fauna in the reservoir. The daily fluctuations of water levels by several metres would yield a devastated strip of riverbank instead of valuable riparian habitats.

Downstream section of Nagymaros

The Nagymaros power plant was also supposed to operate on a peaking mode (*Figure 2.5*). Unlike at Gabčíkovo, there would always be a minimum discharge of at least 1,000 m^3/s. At mode 2000/700 the maximum difference in discharge would still be 1,300 m^3/s with a maximum descent rate of minus 102 m^3/s per minute (Karadi and Nagy, 1993). The maximum decrease of discharge would then correspond to a water level difference of 2 m at the gauge station of Budapest.

Although the daily discharge and water level fluctuations would be smaller than those in the Nagymaros Reservoir, the detrimental impacts on aquatic and riparian habitats would be generally the same.

Peak operation may also result in deformation of the riverbed. Preliminary results of a transport model applied by VITUKI indicate that both accumulation and degradation may be expected in different sections of the river branches along Szentendre island. Because of the danger of riverbed degradation there is no peak operation at the last station of other river barrage systems. For instance at the Rhine, EdF (Électricitée de France) operates the 10 water power stations from Kembs to Iffezheim at a moderate peaking mode (maximum discharge exceeding natural flow Q = 300 m^3/s). Although the peaking of the discharge is considerably smaller than the one at Nagymaros, no peaking is allowed at the last barrage of Iffezheim towards the free flowing river. The reservoir of Iffezheim is merely used for compensation.

The construction and operation of the Nagymaros power plant including peak energy production would probably entail the construction of another barrage at Adony (rkm 1601).

2.3.3 FLOOD PROTECTION IN THE ORIGINAL PROJECT DESIGN

(based on Laczay, 1994b)

The generally accepted level of flood protection for rivers ranges from the 50 to the 200-year flood depending on the value of the endangered area (DVWK, 1983).

Higher protection levels are only applied for large cities, important industrial compounds and nuclear power plants.

With the installation of reservoirs in river systems an additional risk of flooding has to be accounted for. The rupture of a dyke or dam impounding a large body of water may result in higher flood waves than any natural flood event. Therefore the design flood for the safety structures (levees, spillways, flood gates) is generally higher than the design flood for the "normal" dyke system and may go up to the 1,000- or 10,000-year event or to the so-called "Probable Maximum Flood".

Closely associated with the design flood level is the freeboard allowance, which is the safety margin above the calculated water level accounting for wave action, softening of the crest, settling of the dam, etc. Large reservoirs necessitate a higher freeboard, e.g. 2.5 m, as opposed to traditional levees (0.5-1.5 m).

For operational safety it is common usage not to include all available structures for flood release in the calculation but to reserve one or two openings to account for a potential failure of release structures.

In the case of the G/N System the Joint Contractual Plan specified the flood release under various operational conditions, using the Gabčíkovo complex consisting of 8 turbines and 2 ship locks and/or the Dunakiliti weir with 6 gates and 1 ship lock (*Table 2.5*). Several alternative plans for flood operation were considered, the last one, in 1989, stipulated a "Temporary Order of Operation" as follows:

***Table 2.5**: Safety procedure for flood release as stipulated for the Original Project*

Design flood	Gabčíkovo	Dunakiliti		Free-board	Discharge capacity
100-year 10,600 m³/s	release through 4 turbines (50%) and 1 ship lock including the filling system (50%) capacity: 3,920 m³/s	release through 5 openings (77.4%) capacity: 6,680 m³/s		1.5 m	10,600 m³/s (100% of the design flood)
1,000-year 13,000 m³/s	release through 4 turbines (50%) and 2 ship locks including the filling systems (100%) capacity: 5,170 m³/s	release through 6 openings (85.7%) capacity: 7,830 m³/s		0.5 m	13,000 m³/s (100% of the design flood)

For the release of the 10,000-year flood all openings at Dunakiliti should be used. In case of emergency the 100-year flood could be released through Dunakiliti alone with sufficient freeboard.

According to the calculations and model investigations the G/N System provided a suitable release of the design floods with proper safety in case of coinciding structural failures and with sufficient freeboard allowance. The adopted design philosophy complies with international standards.

Ice release

Ice-floes usually develop on the tributaries and on the upper section of the Danube and then drift downstream. If the densely drifting ice stops for some reason, a solid ice cover builds up upstream. If the upstream end of the ice cover catches more and more ice-floes, an ice jam blocking the channel may develop leading to rising water levels. If the ice jam does not start moving, the flow levels may exceed the top of the protecting levees.

Due to the effects of river training the frequency of icy floods has considerably decreased. The last big icy flood occurred in 1956, the last solid ice cover in the Szigetköz reach developed in 1963/64 causing smaller ice jams with no major consequences. Meanwhile only ice drifts occurred, and there was no solid ice cover on the Danube in the last seven winters.

Reservoirs provide lake-like conditions for freezing and the developing ice can amount to enormous volumes. Ice release from reservoirs is the hardest operation to perform, it must be planned and executed with great skill and care.

During almost every winter a solid ice cover up to 30 cm thick would develop. This could lead to an ice jam at the upstream end endangering the city of Bratislava. The following measures were decided on in the Order of Operation in 1978:

> − A solid ice cover should be kept undisturbed as long as possible; the water level should be raised by 0.5 m above the operational level of 131.1 m asl.; no peak power operation; if possible the ice cover should be left to thaw on the spot.

> − In case of strong ice drifts from upstream and/or considerable increase of discharge, an ice free corridor must be provided by ice breakers.

> − The broken ice must gradually be let down through the open Dunakiliti weir; this procedure requires a flow velocity of about 1 m/s which can be generated by lowering the water level to 128.0-128.5 m asl. to provide the appropriate rate of flow. A releasing cycle was planned to last 8-12 hours at 800-1,500 m³/s arriving flows.

In order to direct the broken ice towards the Dunakiliti weir a guiding "ridge" had been built along the left bank of the Danube up to rkm 1847.5. In front of the weir so-called ice catching islands were built to break up large floes of ice in order to avoid possible failure of the gates by blocking. The sill level of the Dunakiliti weir is at 120.7 m asl., yielding sufficient water depth for the safe discharge of broken ice. The entire structure was optimised for ice release. On top of the sector gates tilting gates have been mounted for precise handling of flows. Depending on the actual flow 2, 4 or 6 gates were planned to be raised above the water and the ice. In case of emergency, ice from the headrace canal was planned to be let downstream through the ship locks at Gabčíkovo. It is clear that this procedure of ice release requires a precise and faultless operation of the weir gates.

2.4 IMPACTS OF VARIANT C

2.4.1 CONSTRUCTION

Čunovo Reservoir

The Hungarian part of the projected Dunakiliti-Hrušov Reservoir is not impounded, but the floodplain vegetation and the side branch system were already devastated in 1989, when Hungary suspended work at the Dunakiliti weir structures. The Slovak part of the reservoir was constructed more-or-less according to the Original Project design with a connecting levee to the dyke of the power canal. The detrimental effects of the Čunovo Reservoir are the same as of the original Dunakiliti-Hrušov Reservoir.

The present operation of Gabčíkovo without peaking would not require an operational reservoir volume. If Gabčíkovo was just used as a run-of-river power plant the Čunovo Reservoir could be much smaller, constricted to the main channel without impounding the former floodplain.

2.4.2 OPERATION

Čunovo Reservoir

There is no information on the daily operation mode of Gabčíkovo. Presumably the system is working at constant discharges without peaking although a sudden increase in the discharge was reported in July 1994 causing fish mortalities in the old riverbed (see *Chapter 5.4*). Thus, there are only minor water level changes in the reservoir on a daily basis.

During the first flood after the closure of the river in November 1992 the downstream channel and floodplain were severely eroded due to unfinished protection measures and some tainter gates were washed away (cf. *Chapter 2.4.4*, below).

The high amount of eroded material is intermittently transported along the Old Danube during the flood discharge releases and finally contributes to the riverbed aggradation between rkm 1808-1800 (see *Chapter 2.4.3*). This process can still last for several years.

Table 2.6: Hydro-morphological impacts of Variant C on the Old Danube

OLD DANUBE	
Discharges	• base level flow releases from Čunovo (based on daily measurements at river gauge Rajka): November 1992-March 1993: 200-250 m³/s April/May 1993: about 300 m³/s June/July 1993: 300-350 m³/s August/December 1993: 250-300 m³/s January/September 1994: about 200 m³/s • flood discharge exceeding 3,000 m³/s were released in the old riverbed.
Water levels	• sudden drop of water levels by 2-3 m (CEC, 1993a)
Flow velocities	• reduction of flow velocities from the former 1.2-2.0 m/s to about 1.0 m/s (CEC, 1993b); • reduced flow velocities in the tailwater of the power canal conjunction
Fluctuations of discharges & water levels	• 6 flood discharges up to 2,430 m³/s were released until December 1993; one flood discharge amounting to 1,960 m³/s was released until September 1994. • unnaturally sudden rise and drop of discharges (and water levels) during flood release
Riverbed stability	• bank failures caused by the sudden drop of water levels after damming the Danube; • gradual degradation of the riverbed can be expected as predicted for the Original Plan (Bačik *et al.*, 1992)
Riverbed structures	• gradual formation of a riverbed adapted to flows of about 200 m³/s; destruction of riverbed structures could be expected at rare flood events rapidly released at Čunovo.
Riparian structures (ecotones)	• formation of a new riparian zone which is better adapted to flood discharges than it would be according to the Original Project

Old Danube

There is not much difference in hydro-morphological impacts between the Original Project design and Variant C. The discharges released to the Old Danube since the damming of the river, were kept on a base level of 200-250 m^3/s with an increase to about 350 m^3/s in the vegetation period of the first year of operation. In 1994 the discharges were kept to a base level of about 200 m^3/s and were not increased in the summer. Consistent with the discharge capacity of the 6 turbines at Gabčíkovo, flood discharges exceeding 3,000 m^3/s were released in the Old Danube.

Although no monitoring data of the riverbed structures were available, it can be expected that the riverbed will eventually develop structures adapted to the base flow and to a certain range of flood flows. Major changes in bed morphology could be expected during rare flood events. Vegetation grows and spreads between flood events on the formerly inundated part of the riverbed, decreasing its discharge capacity.

Although one-tenth to one-fifth of the discharge of the river is directed to the Old Danube, the actual increases of the every day water levels produced by the operation of Variant C are insufficient for the existence of floodplain habitats. In addition, similar degradation of the riverbed in the medium and long term has to be expected due to the total retention of the bedload in the reservoir.

The effect of "underwater weirs" is discussed in *Chapter 2.5* below.

The Szigetköz floodplain

The implementation of Variant C with all remedial measures will not improve the situation of the Szigetköz floodplain compared to the detrimental impacts anticipated in the Original Project. The base discharge of about 200-250 m^3/s resulted in a considerable drop of the groundwater-table adjacent to the river (see *Plate 3.14*). In addition, the flood stages do not last long enough for efficient groundwater recharge.

On the Hungarian side, the desiccation that started in the mid-1960's with the overdredging of the riverbed will eventually result in a total loss of the wetlands. On the Slovak side, the impoundment of the side branch system will change the riverine wetland character comprehensively (Chapter 4).

Table 2.7: Hydrological impacts of Variant C on the Szigetköz floodplain

SZIGETKÖZ FLOODPLAIN	
Discharges	• constant supply for the side branch systems: 2-10 m³/s on the Hungarian side • flow in a few side branches from the Danube when releasing 1,800-2,500 m³/s at Čunovo weir gates • flow in some side branches at a release of 2,500-3,500 m³/s; • flow in almost all side branches at a release of 3,500-4,500 m³/s (CEC, 1992)
Groundwater-table	• drop of the groundwater-table near the Danube corresponding to the 250 m³/s water level • insufficient recharge of the groundwater by the side arm system at least on the Hungarian side; pumping of Danube water into the Szigetköz since July 1994 • on the Slovak side a higher groundwater-table is maintained by the implementation of a cascade system in the side branches • clogging has to be expected in large areas on both sides
Fluctuations of the groundwater-table	• the duration of the flood discharges in the side branches will be too short to result in significant fluctuations of the groundwater-table
Floodplain morphology	• until 1967/68 flushing of side arms with more or less scouring, deposition and lateral movement occurred several times a year; this is now limited to rare events with flood discharges shared between the power canal and the Old Danube; • deposition of a considerable part of the incoming suspended sediment load in the Čunovo Reservoir reduces the sediment input into the floodplain
Floodplain habitats	• desiccation of almost all wetlands in the Hungarian Szigetköz floodplain within a short period of time • only narrow riparian strips along those side arms that are supplied with constant discharge will keep their wetland character • on the Slovak side the previous riverine wetland habitats will lose their character due to missing relevant fluctuation of the water level in the impounded side branch system • stagnancy in the evolution of all habitats due to missing dynamics of waterflow, water levels and sediment input

2.4.3 IMPACTS OF VARIANT C ON NAVIGATION

After closure of the Danube in late October 1992, navigation was directed through the power canal using the locks at Gabčíkovo. Accidents at both locks interrupted navigation in early 1994 for several weeks, since the Old Danube could not be used for navigation during the incomplete status of Phase 1 (no ship lock installed at the Čunovo complex).

Since the diversion of the flow through the power canal several new flood sections have developed downstream of Sap between rkm 1808-1800 restricting the available low-flow depths by several decimetres.

2.4.4 FLOOD PROTECTION IN VARIANT C

(based on Laczay, 1994b and OVIBER, 1994)

Flood release

While the Dunakiliti weir was ready to release all the floods as planned, the structures at Čunovo were in various stages of construction when the Danube was closed by October 27 in 1992. In Phase I only the by-pass weir and the floodplain weir (plus the intake for the Mosoni Danube) could be used for flood release at the Čunovo structure. In addition, the construction of these weirs was not finished at the time of the dam closure. As stated in the CEC Working Group Report of 1992 (p. 8), on November 22, 5 out of 20 tainter gates of the floodplain weir were not mounted yet and only 10 of the gates had a short downstream bed protection of 10 instead of 50 m. At that time 5 turbines had been installed at Gabčíkovo with a capacity of 610 m^3/s each, the two ship locks had a maximum discharge capacity of 1,970 m^3/s (CEC, 1992, p. 4). There are several different discharge capacities for the turbines in different sources, ranging from 500 to 610 m^3/s; the calculation is based on 570 m^3/s used by OVIBER (1994).

The hydraulic capacity for flood release of Variant C has to be measured at the same safety standards that were adopted for the Original Project (*Chapter 2.3.3.*). This means that the release of the 100-year and the 1,000-year flood, respectively, should not use the entire discharge capacity available and sufficient freeboard allowance should be left. In addition, in case of emergency the Čunovo structure should be able to convey the 100-year flood alone.

This is obviously not the case for Phase I of Variant C. The operational guidelines, presented by the Slovak side to the Borders Water Commission in 1993, said that for the 100-year flood (calculated to be 10,600 m^3/s) 4,820 m^3/s should be released

through Gabčíkovo. This means that 5 out of the 6 turbines so far installed and both ship locks would need to be used, using 89% instead of the previous 50% of the discharge capacity. In this case Čunovo would have to release 5,780 m³/s compared to an available capacity of 6,085 m³/s which is 95% (CEC, 1992). Actually this discharge capacity was not available immediately after the closure of the Danube; the Čunovo complex could hardly manage the 2,250 m³/s that had to be released during the November flood in 1992.

OVIBER (1994) calculated the available discharge capacity of Phase I considering the safety conditions which were adopted in the Original Project (*Table 2.8*). According to these calculations the design floods could not be released in Phase I with the same safety standards as in the Original Project. In addition, in case of emergency the Dunakiliti weir would have, in the Original Plan, been able to release the 100-year flood alone with a smaller freeboard allowance. This again, is not possible with the Čunovo structures in their present condition (Phase I).

With the completion of Phase II (by the end of 1995?) the Čunovo structure will be able to discharge an additional 6,300 m³/s through a ship lock, spillway gates and small turbines (CEC, 1992). Then the total discharge capacity will be 17,585 m³/s, exceeding the 10,000-year flood.

It can be concluded that the Slovak side has accepted additional risks when implementing Variant C with uncompleted flood release structures called Phase I. In case of an uncontrolled rise of the water level up to the crest of the reservoir dyke, large protected areas in the Szigetköz could possibly be endangered by inundation.

Since the closure of the Danube three major floods occurred. Considering the incomplete flood release structures of Phase I, it was only good luck that the unusual November flood did not cause more damage. Although only 2,250 m³/s had to be discharged through the Čunovo weir, about 3 million m³ of sediment were washed away from the downstream floor of the bypass weir and the floodplain weir. A longer flood release could have endangered the weir structure. The damage to protecting structures, cross-dykes in the side arms, etc., on the Hungarian side amounted to around 11 million HUF. For further long-term consequences of this event, see *Chapter 2.4.2*.

In July 1993, a common summer flood with a discharge peak of about 5,100 m³/s occurred; although there is a mutual agreement for joint action in flood fighting, there was no prior information on the actual flood release at the Čunovo weir. Within a few hours the discharge in the Old Danube was raised from 350 to about 1,600 m³/s which was followed by a decrease to 750 m³/s and another increase to 1,600 m³/s within the next two days. These rapid water level fluctuations resulted in similar damage to the Hungarian side branches as in November 1992.

Table 2.8: Safety level at flood release for Variant C, Phase I (as calculated by OVIBER, 1994).

Design flood	Gabčíkovo	Čunovo	Free-board	Actual Discharge Capacity	Missing discharge capacity
100-year 10,600 m³/s	release through 3 turbines (50%), 1 ship lock including the filling system (50%); capacity: 3,530 m³/s	release through 15 gates of the floodplain weir (75%), 3 gates of the bypass weir (75%); capacity: 5,310 m³/s	1.5 m	8,840 m³/s (83% of the design flood)	1,760 m³/s
1,000-year 13,000 m³/s	release through 3 turbines (50%), 2 ship locks including the filling systems (100%) capacity: 4,630 m³/s	release through 18 gates of the floodplain weir (90%), 3 gates of the bypass weir (75%); capacity: 6,150 m³/s	0.5 m	10,780 m³/s (83% of the design flood)	2,220 m³/s

Ice release

As stated above (*Chapter 2.3.3*) the release of ice floes and broken ice is a delicate operation, and the installation of a large reservoir promotes the development of an ice cover. Slovak authorities have presented insufficient information about the planned handling of icy floods. Supposing a similar release operation as originally planned at Dunakiliti, some questions arise.

The sill levels of the bypass and floodplain weirs at Čunovo are at 126.5 m asl. and 128.0 m asl., respectively, compared to 120.7 m asl. of Dunakiliti. This means, that the reservoir level cannot be lowered enough to safely discharge the broken ice (water depths of less than 2.0 m at the sills of the gates must be regarded as unsafe for ice release). On the other hand higher reservoir levels than 130.0 m asl. would not result in the required flow velocities to move the ice towards the gates.

As opposed to the Dunakiliti release structures, no tilting gates have been mounted at the Čunovo sector gates which would allow more precise gate operation. In addition, no ridges were constructed to guide the broken ice towards the Čunovo gates.

These conditions led to a dangerous situation in January 1993 when drifting ice accumulated in front of the Čunovo structure, and the ice flow turned into the power canal. Subsequently a 1.5-2 m thick ice jam developed in rkm 11.2-13.4 which could not be removed by ice breaker actions. Navigation was stopped for a week until the problem was solved by a thaw.

It can be concluded, that in terms of ice release, the Variant C structures cannot fulfil the requirements of the Original Project plans and can lead to blockage of navigation.

2.5 EVALUATION OF REMEDIAL MEASURES ("UNDERWATER WEIRS")

The term "underwater weir" disguises the fact that the proposed structures are regular fixed weirs of several metres height with backwater reaches of several kilometres in length (*Table 2.9*). At normal flow conditions in the Old Danube, i.e., 50/200 m^3/s for the Original Project and around 200 m^3/s base flow for Variant C, the free flowing Old Danube would be turned into a sequence of impounded reservoirs (*Figure 2.7*). As a matter of fact, there are plans to install small hydropower units in each weir structure.

Experiences from the Upper Rhine at the barrage of Rhinau (*Plate 3*) with similar weirs in the "rest-Rhine" show that such weirs may not have the desired effects on the adjacent groundwater levels. Kalkowski (1986) compared water levels for surface and groundwater with pre-dam conditions after 20 years of operation of the barrage of Rhinau (operating since 1964). He found:

– that the measured surface water levels up to a total discharge of 1,500 m^3/s (i.e., 15 m^3/s in the "rest-Rhine") are lower at the upper end of the impoundments than the average annual water level for pre-dam conditions,

– that even at flood flows the weirs are hydraulically effective and no continuous water level exists at any discharge,

– that the gradient of the groundwater level does not follow the drop of the surface water level at the weirs,

– that the groundwater level is governed by the low surface water levels at the upper end of the impoundments and not by the higher impounded levels near the weirs. For instance, the average groundwater-table adjacent to the channel of the dry year 1976 was almost identical with the pre-dam low flow water level of the Rhine in 1961, although the impoundments rise the surface water levels 70-80 cm above the previous average water level of the river.

These findings show that the construction of "underwater weirs" cannot replace the natural regime of the former river with respect to groundwater levels. Considering the absence of water level fluctuations up to 1,500 m^3/s (mean flow at this section of the Rhine ca. 1,100 m^3/s), the changes imposed on the groundwater regime by "underwater weirs" significantly affects the wetland ecosystem in the floodplain.

Table 2.9: Location, height, and width of "underwater" weirs as proposed by the Slovak side (CEC, 1993b)

Location (rkm)	Height (m)	Width (m)
1814.21	5.85	210
1816.60	3.10	290
1821.30	3.80	270
1824.43	4.95	270
1828.35	4.05	270
1831.70	3.95	300
1834.90	4.15	230
1843.00	4.05	300

In addition to the water levels, *Figure 2.7* shows the velocity profiles of the Old Danube for 50, 200 and 350 m^3/s with and without "underwater weirs" as proposed by the Slovak side (*Table 2.9*). Three phenomena can be observed from these graphs:

-with "underwater weirs" the flow velocities would be reduced to about one third of flow conditions, without backwater effects,

-without "underwater weirs" the variability of the flow velocity along the river is considerably larger,

-the backwater from the conjunction with the power canal affects the Old Danube up to rkm 1820-1825.

The magnitude and variability of the flow velocity govern the morphological pattern of the remaining riverbed. The construction of "underwater weirs" would lead to rather uniform flow conditions with the consequence of rather uniform riverbed habitats. Prevailing low flows during most of the year would lead to the silting up of a great part of the remaining riverbed; flood discharges would wash out most of these fine sediment. Thus the series of "underwater weirs" would represent nothing else than a sequence of weirs with backwater reaches in a small river with the well known resulting changes in the aquatic habitat.
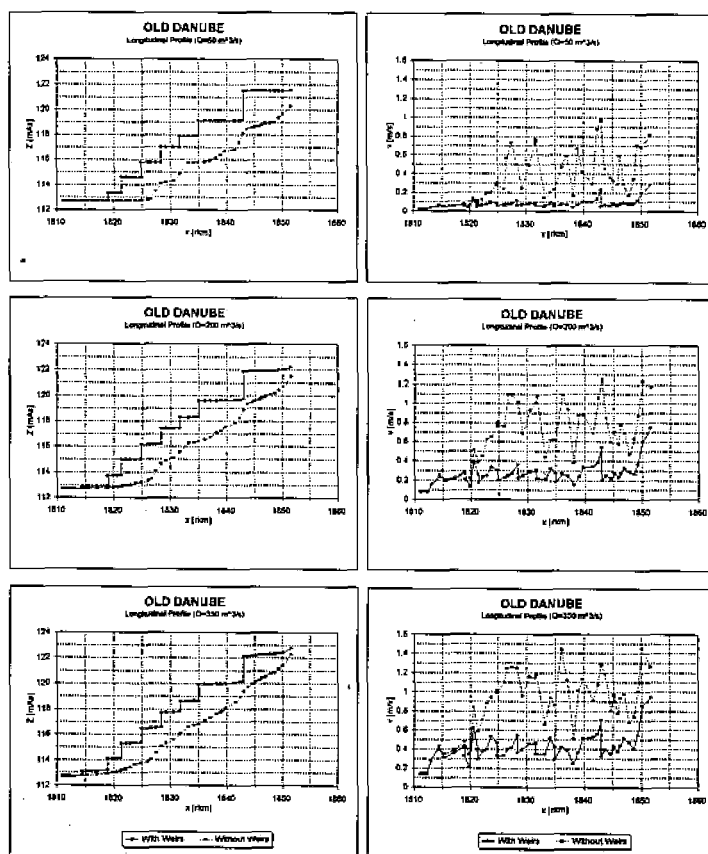
Figure 2.7: *Water levels and velocity profiles in the Old Danube with and without "underwater weirs" for 50, 200 and 350 m³/s (no peak operation at Gabčíkovo) (produced by VITUKI Consult Rt in September 1994)*

2.6 ALTERNATIVE MANAGEMENT STRATEGIES

2.6.1 RIVERBED DEGRADATION

It is claimed in the Slovak Memorial that the problem of riverbed degradation is one of the main reasons for the implementation of the G/N Project (SM, paras 1.18, 2.85, 2.86). It has been stated above that in the Hungarian reach of the Danube the elevation of the riverbed is closely related to deposition of sediment and the impacts of dredging. There is no indication that the reduced level of sediment supply from upstream or river training has caused degradation of the bed. No certain conclusion can be drawn for the Slovak river reach because of the lack of dredging data.

In the case that bed degradation would have to be prevented by other means than stopping the industrial exploitation of gravel (and moving it to the floodplain), international experience points to less detrimental solutions than barrage building (Kern, 1994b).

At the Upper Rhine, barrage construction ended in 1977 with the barrage of Iffezheim. In 1975, France and Germany signed a treaty stipulating the construction of still another barrage at Neuburgweier mainly to prevent the down-cutting of the river below Iffezheim. Already in 1970, Karl Felkel published a paper with the title "Reflections on the possibility of preventing erosion of a movable riverbed –Upper course of the Rhine River taken as an example" (Felkel, 1970). After a series of field tests with sediment addition to replace the eroded bed material starting in 1975 below the barrage of Gambsheim (operating since 1974), Germany and France agreed in 1978 to continue the tests below the barrage of Iffezheim. In 1982, both countries signed an amendment stipulating that sediment addition would be carried out below Iffezheim instead of barrage construction at Neuburgweier. This decision was based on ecological as well as on economic considerations.

Between 1978 and 1992, a total volume of 2.3 million m^3 of gravel was added to the riverbed. As a result the navigational low-flow water level could be maintained within the prescribed margins. Intensive monitoring of the riverbed proved that the sediment addition is a feasible solution to riverbed degradation.

Encouraged by the Upper Rhine experience, preliminary field tests are being carried out in the Austrian reach of the Danube to stabilise the river below the last barrage, although only slight erosion tendencies were predicted there. Unlike at the Upper Rhine, the Austrian sediment addition is intended to develop an armoured layer of coarse sediment rendering a permanent bed protection which not only resists the hydraulic forces of flood flows but also of ship propellers. General model tests proved the feasibility of this procedure (Kern, 1994b).

2.6.2 NAVIGATION

(based on Laczay, 1994a)

Both the Danube Commission and the EEC regulations require 2.5 m draft with a minimum underkeel clearance of 0.2 m. The EEC and the DC recommend a fairway width of 80 m and 100 m, respectively.

The river training concept adopted in the early 1960s (*Chapter 2.2.3*) stood on sound scientific and professional grounds. Due to expected impoundment effects of the planned G/N Project, construction was not fulfilled on the entire reach. Along the stretch rkm 1842-1816, from Rajka to Sap, where training measures have been consistently performed, conditions of navigation improved and achieved a tolerable level. Apart from a few deficiencies in width, no major obstacles or

"bottlenecks" were known in this particular reach. Shallow sections near Dunakili-ti were caused by the construction of the inlet and outlet canal of the Dunakiliti weir.

In a re-evaluation of traditional concepts of navigational river training, it was concluded by VITUKI (1991) that a traditional solution without canalisation by major structures may be feasible, provided that careful morphological studies have been carried out. The special situation of this aggrading Danube reach will probably require some permanent maintenance. Similar conclusions were drawn by a recently completed Dutch-Hungarian study (Delft, 1994).

It is common practice in traditional river training to perform some dredging for navigational purposes, e.g. at the Rhine, the busiest fairway of the world, permanent dredging has to be carried out to maintain the required navigational depths (BMV, 1987).

2.6.3 FLOOD PROTECTION

In terms of flood protection there is and was no need for the G/N Project. The provisional construction of Phase I of Variant C might lead to an uncontrolled flood release, even in protected areas of the Szigetköz.

With the construction of a relatively large reservoir, ice conditions of the river have deteriorated. As opposed to pre-dam conditions, the development of a solid ice cover has to be anticipated almost every winter. Discharging ice from a reservoir is a most delicate task imposing additional risks, even with appropriate construction and proper operation. The structures of Variant C, Phase I, do not even fulfil the design requirements which were agreed for the Original Project.

Especially downstream of Győr there are some areas with insufficient flood protection on the Hungarian side where the dykes need to be heightened. The completion of the Slovak Reservoir dykes in this section *after* Hungary abandoned the G/N Project puts Hungary in an unfavourable situation because these dykes are 0.2-0.6 m higher than the required 100-year flood level. So Hungary will be forced to raise the dyke system in this reach to the same level to prevent increased and unacceptable risks from a higher level of flooding.

2.7 CONCLUSIONS

It was claimed in the Slovak Memorial, that the G/N Project is the *only* reasonable solution

- for harnessing the potential energy of this river reach;
- for solving flood protection problems;
- for mitigating navigation problems; and
- for solving the problems of bed degradation.

FLOOD PROTECTION

It is pointed out in this chapter that there was no need of this project to solve flood protection problems. Repeated reinforcements of the dyke systems after large floods have eventually led to an appropriate level of flood protection in the flood prone areas of the Szigetköz. Downstream of Györ minor tasks for flood protection have to be fulfilled. As a matter of fact, the installation of a large reservoir has increased the potential danger of ice problems, and the incomplete state of construction of Variant C, the so-called "Phase I", imposed additional risks on both sides.

NAVIGATION

There is clear evidence that the remaining obstacles for navigation can be removed by traditional river training methods including regular maintenance on short reaches. The Danube Commission requirements in depth for free flowing river sections can be met over the entire reach without a barrage system. Thus there is no reason to talk about a bottleneck in an important international fairway. The remaining restrictions in width and radii can be handled by careful navigation. The diversion of the Danube to the power canal has caused some additional ford sections downstream of Sap.

BED DEGRADATION

Unlike at the river Rhine, the degradation of the Danube bed in the Hungarian-Slovak reach and the subsequent lowering of the low flow levels was caused by excessive gravel mining combined with ford dredging and not by river regulation or bedload retention of upstream dams. The G/N Project simply compensates for the sinking of the water levels by impounding the free flowing river including the side branch system while ignoring the basic essentials of wetland ecosystems. Those who pretend to "save the Danube's inland delta" merely ignore the adverse environmental effects of the G/N Project.

ENERGY PRODUCTION

The entire G/N System was optimised for energy production. The construction of a large reservoir and the size of the power canal as well as the downstream barrage of Nagymaros were necessary for peak operation. Daily water level fluctuation up to 4.5 m in the Nagymaros reservoir had been accepted by the project planners caused by rapid daily rise and fall of the discharges released at Gabčikovo during peak operation. For optimal use of the discharge at the turbines only 50 m^3/s should be released in the old riverbed during most of the year. The detrimental

impacts on the aquatic and riparian flora and fauna in the entire project reach have been emphasised in this chapter. Even at Nagymaros a considerable peaking operation was planned with high variability of releases to the free flowing river. The characteristics of the peaking are unmatched in European navigational lowland rivers, contrasting with the Slovak statement that the G/N Project is just another normal barrage system, similar to others in Europe.

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CHAPTER 3

SURFACE AND GROUNDWATER

SUMMARY

Riverbed aggradation below Bratislava has led to the formation of the wetland systems of the Szigetköz and Žitný Ostrov, located on a deep alluvial cone which forms the largest high quality groundwater aquifer in Central Europe. The Danube flows have regularly flushed the complex system of side-arm branches, but the Danube main channel has primarily determined the groundwater recharge and groundwater levels throughout the Kisalföld.

Further downstream, the alluvial aquifers are much less extensive, but nevertheless are widely used for bank-filtered groundwater supply, including the supply to Budapest. In addition, there is some limited connection with the Karst groundwater of the Transylvanian mountains.

SURFACE WATER QUALITY

Historical trends of surface water quality show a dramatic increase in the nutrients Nitrogen and Phosphorus, which are no longer limiting for eutrophication. Increased algal biomass has occurred, and a change in phytoplankton communities. Bacteriological quality remains poor. Some heavy metal concentrations in water exceed permitted values; similarly heavy metals in sediment sometimes exceed relevant standards. The highest pollutant concentration tend to be associated with the fine sediment fractions.

Impacts of the Original Project in terms of water quality were neglected in the early studies of environmental impact, and even today have yet to be fully explored. One example is the effect of peak power operation on the Mosoni Danube. Flow reversal is likely to lead to unacceptable water quality given either wastewater discharges or stormwater overflows. A second example concerns the effects of the dams on eutrophication. Recent simulation results show a near-doubling of algal biomass due to the Dunakiliti Reservoir, and the effect of increased biomass on biochemical oxygen demand can exceed the impacts of wastewater discharges. However, prediction uncertainties remain high.

Anticipated effects of Variant C are similar in many respects, although Variant C is less unfavourable with respect to eutrophication. Current observations of water quality for 1993 and 1994 show some conflicting trends and are insufficient to

identify long-term effects. Adverse water quality changes in the Mosoni Danube lead to fish mortalities.

GROUNDWATER

Prior to the diversion of the Danube, groundwater levels throughout the Szigetköz and adjacent areas were determined by Danube water levels. In addition to the direct supply to vegetation from near-surface groundwater, capillary rise can provide a significant source of natural sub-irrigation, where groundwater levels reach the covering fine soil horizons. The typical seasonal pattern of Danube flows generated maximum groundwater levels in the summer period of maximum water requirement for plants.

Some groundwater from the Szigetköz is used for supply, but the resource is as yet largely unexploited. Estimates of yield are similar to the needs of a capital city such as Budapest. The smaller alluvial aquifers downstream are more extensively used, in particular for the Budapest water supply.

Impacts of the Original Project have been investigated by groundwater simulation. The regional flow patterns change radically. The primary recharge sources become the reservoir itself and the side-arm system. Groundwater increases occur near the reservoir, but decreases in groundwater levels are predicted to exceed 3 m and to affect an area of approximately 300 km^2 on the Hungarian side. Sub-irrigation would be reduced or lost over 167 km^2. However, results are sensitive to the uncertain effects of clogging associated with the deposition of fine sediment.

Further downstream, there is a likely degradation of Karst waters due to backwater effects of the Nagymaros dam, but the main issues concern bank-filtered wells, which are considered separately.

Impacts of Variant C are quantified for the Szigetköz and adjacent areas. These are shown to vary, depending on the level of former Danube flows. Up to 240 km^2 have suffered reduced groundwater levels. Under high flow conditions, 22 km^2 suffer reductions in excess of 3 m. In comparison with 1990, 127 km^2 suffered reductions in groundwater sub-irrigation during the growing season.

GROUNDWATER QUALITY–THE SZIGETKÖZ AND ADJACENT AREAS

Under natural conditions, recharge from the Danube is of high chemical quality and this water determines the present groundwater quality. However, sediment deposition in the side-arms has led to important chemical changes. Organic decay consumes oxygen; under reducing conditions, iron, manganese, and ammonium are readily released.

There are serious concerns for groundwater quality associated with the Original Project. Sediment deposition in the Dunakiliti Reservoir is expected to decay, and may lead to the water quality problems outlined above. This is confirmed by international experience and acknowledged by Slovakia and the CEC Fact-Finding Mission. Predictions are highly uncertain, but suggest that such occurrence is likely in the reservoir. These effects are already observed in the side-arm system, which would become the other main source of groundwater recharge. There is a significant risk that the aquifer, over a period of years and decades, would become unfit for water supply.

Following construction of Variant C, groundwater quality adjacent to the side-arm system has generally been found to have unacceptable levels of iron, manganese, and ammonium, with some examples of arsenic release.

BANK-FILTERED WATER SUPPLIES

Concern for bank-filtered water supplies includes problems of yield and chemical quality. Where gravel layers in the riverbed have been reduced, for example, in the vicinity of Budapest, well yield has been reduced and there is an increased risk of pollutant ingress. Changes to river sediment have also led to the deposition of fine sediment adjacent to wells, with observed long-term water quality deterioration, documented here for the Surány Waterworks on Szentendre Island.

In the back-water reach of the Nagymaros dam, sediment deposition is calculated to affect the quality of existing waterworks. Just downstream, two existing wells have had serious water quality degradation due to bed sediment changes, believed to be associated with the Nagymaros coffer dam.

Downstream of Nagymaros, dredging was to have taken place and simulations show that further bed degradation is expected due to erosion. These effects are compounded by changing patterns of sediment deposition. It is concluded that there is a serious risk of yield reduction and water quality deterioration in the major well fields providing water supply to Budapest.

3.1 INTRODUCTION

3.1.1 THE NATURAL SYSTEM

As noted in *Chapter 2*, the Danube emerges from a gap between the Alps and Carpathian mountains at Bratislava to flow through the Kisalföld, or Little Danube Plain, to the Danube Bend and Budapest (*Plate 1.1, Volume 5*). River morphological development was discussed to explain the history of riverbed aggradation

and the formation of the complex wetland systems of the Szigetköz and the Žitný Ostrov. On the geological time-scale a large alluvial cone has been formed, which reaches depths of 600 m in the Szigetköz and forms a groundwater aquifer which is the largest groundwater resource in Central Europe. Downstream of Gönyü, the gravel layers are substantially thinner, and discontinuous, but they have been extensively developed for bank-filtered water resources, and in particular for water supply to Budapest, where some 800 wells supply up to 1 million m^3 per day.

Throughout the Danube reach from Bratislava to Budapest, there is an intimate interrelationship between surface waters and groundwater. The dominant source of recharge to the alluvial groundwater is in general the main Danube channel. Hence groundwater levels are primarily determined by Danube water levels, and their temporal variability reflects the Danube flow regime. This has also been the case for the Szigetköz, although the situation is more complex, due to the periodic filling of the braided system of side-arm channels under high Danube flow conditions.

The Danube flow regime and associated groundwater levels have had a dominant and defining influence on the regional environment. As discussed in *Chapter 5*, this is reflected in the patterns of soil development. In *Chapter 4*, the ecological dependence on these hydrological characteristics is presented. It should be noted that where shallow groundwater occurs, it may be directly accessible to vegetation. However, if the water-table is located within a fine-textured soil profile, capillary action can provide a significant plant water supply through a natural process of sub-irrigation. This has been an important factor in both the natural ecology of the Szigetköz and the agricultural development of this region.

It can be seen that the natural systems of the region, and particularly the Szigetköz and adjacent areas, have evolved, over a time-scale of centuries and longer, to form an integrated system with complex inter-dependencies.

3.1.2 METHODOLOGY OF IMPACT ASSESSMENT

The aim of this chapter is to explain our understanding of the surface water and groundwater regime under pre-dam conditions, and to discuss the actual and potential impacts of the Original Project and Variant C. However, the complexity of the problem, involving physical, chemical and biological inter-relationships, some of which are poorly understood, should not be underestimated, nor the methodological implications.

To illustrate the complexity, it can be noted that changes in Danube flows affect groundwater directly, but also have impacts on surface water quality and the de-position/mobilisation of river sediment. In turn, the distribution and depth of sediment modify surface water-groundwater inter-relationships, and chemical changes in surface water and sediment can have major implications for groundwater quality.

Methodologically, the only way to quantify change in such a complex set of inter-related processes is through simulation models based on extensive field data, but model strengths and limitations must be clearly understood. The application of integrated models to such complex systems is at the leading edge of research, and it must be recognised that techniques available for uncertainty analysis of such complex models are limited, and that levels of uncertainty may be very high. For example, although simulation methods for sediment transport are well developed, their results, particularly for bed-load, are typically subject to order of magnitude uncertainty. Processes of sediment clogging have received relatively little scientific attention, and there is no agreed basis to quantify effects on groundwater recharge. Modelling of chemically reductive processes in sediment and groundwater is in its infancy, and predictive results should be regarded as speculative, at best. It is evident that the combined models should therefore be seen as a way of informing judgement on impacts of change, but levels of uncertainty must be recognised in the context of risk assessment.

In our view, an integrated programme of modelling is an essential prerequisite for an environmental impact analysis of the Original Project. This is clearly recognised on the Hungarian side (Somlyódy et al., 1989), and equally clearly recognised by Slovak and international experts. For example, Mucha (1990), discussing groundwater quality, notes process complexity, lack of knowledge, and the need for modelling. "In addition, biological and microbiological activity plays a decisive role in the game of groundwater quality considering the whole system from rainfall to the rivers, soil and the groundwater itself. . . .We must admit that this system and the processes occurring in it are not fully understood. It is an unquestionable fact, however, that such a complex system can be examined only by means of a model . . ." Discussing the PHARE project, Refsgaard et al. (1994) note that "To understand and analyse the complex relationships between physical, chemical and biological changes in the surface and subsurface water regime requires multidisciplinary expertise in combination with advanced mathematical modelling techniques" and conclude that information from the integrated modelling system "constitutes a necessary basis for subsequent analysis of flora and fauna in the floodplain."

However, Mucha also clearly recognises the limitations of modelling as well as its strengths. To continue his previous quotation, ". . .by means of a model, which nevertheless are still far from simulating the real complexity of the process. Last but not least, we are not even able to define our common understanding of nature conservancy and groundwater protection."

On both the Hungarian and Slovak sides, strenuous efforts are being made to quantify potential impacts using advanced modelling methods, and results from ongoing Hungarian studies are reported below. However, we reiterate our view, reinforced by Mucha and Refsgaard et al., above, that such modelling is, and was seen in 1989 to be, an essential prerequisite for environmental impact assessment. It is, additionally, our view that such assessment is and was essential prior to

proceeding with the Original Project. The fact remains that it is not yet fully in place on either side.

3.1.3 SCOPE OF THE CHAPTER

In the following sections surface flow characteristics of the natural system, Original Project *(Plate 1.1, Volume 5),* and Variant C *(Plate 1.2, Volume 5)* are briefly defined *(Chapter 3.2),* surface water quality is reviewed in *Chapter 3.3,* and the succeeding three sections evaluate the groundwater flow system *(3.4),* groundwater quality aspects of the Szigetköz and adjacent areas *(3.5),* and finally consider impacts on bank-filtered wells in the lower reaches (Gönyü to Nagymaros and Nagymaros to Budapest).

3.2 SUMMARY OF SURFACE WATER HYDROLOGY

by Klaus Kern

3.2.1 THE NATURAL SYSTEM

The discharge regime of the Danube is characterised by a seasonal variability which is governed by the Alpine catchment of the river, yielding higher discharges in early summer (mean annual flood 5,300 m^3/s) and a low-flow period in the winter (average 848 m^3/s). *Figure 3.1* shows the long-term monthly hydrograph of the Bratislava gauge.
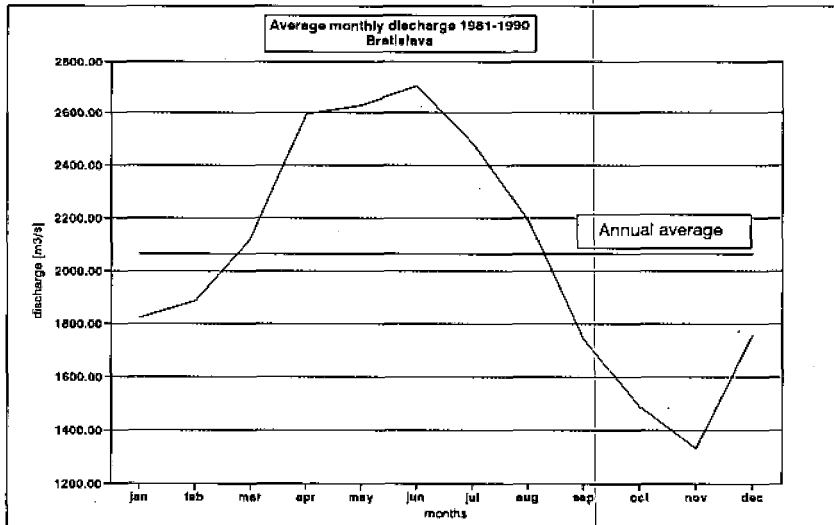
Figure 3.1: Average monthly discharge at Bratislava between 1981 and 1990

The design of the Original Project was based on the following characteristic discharges at Bratislava and Nagymaros (JCP. 0-1, 1977):

	Bratislava	Nagymaros
Period:	1901-1950	1901-1950
Average flow:	2,025 m³/s	2,421 m³/s
Lowest flow (year):	570 m³/s (1948)	590 m³/s (1947)
Highest flood (year):	10,400 m³/s (1954)	8,180 m³/s (1965)
20 year flood:	8,750 m³/s	7,650 m³/s
100 year flood:	10,600 m³/s	8,700 m³/s
1,000 year flood:	13,000 m³/s	10,000 m³/s
10,000 year flood:	15,000 m³/s	11,100 m³/s

Before the degradation of the riverbed started in the 1960s, many of the side branches were still open. The discharge in the side branches of the Szigetköz and Žitný Ostrov, e.g. in the reach of Gabčíkovo (rkm 1833-1816), amounted to about 20% for a total discharge of 1,005 m³/s. At 1,958 m³/s which is exceeded on 168 days per year the side branches carried up to 500 m³/s (Mucha, 1993).

After degradation of the riverbed and the closure of entrances of side-arms to improve navigation, the threshold for the branch system inflow increased to 2,500 m³/s which typically occurs for 75-100 days per year.

The following data in *Table 3.1* represent the situation in 1980.

Table 3.1: Flow regime of the Danube in 1980 (after CEC, 1992 and WORKING GROUP REPORT, pp. 16-17)

Characteristic flow situation	Discharge 1980-conditions (m^3/s)	Water levels at Dunaremete (m)	Flow velocity in main channel at Dunaremete (m/s)	Average duration (days/year)	Frequency (events/year)
Flow largely confined to groynes within main channel	< 1,000	2.3	→ 1.4	13 days	Several times per year
Flow in main channel and permanent branches	1,000-1,800	3.7	1.4-1.8	42 days	Several times per year
Flow in a few river arms	1,800-2,500	3.7-4.5	1.8-2.0	122 days	Several times per year
Flow in some river arms	2,500-3,500	4.5-5.2	2.0-2.2	78 days	Several times per year
Flow in almost all river arms	3,500-4,00	5.2-5.6	2.2-2.3	17 days	Several times per year
Complete inundation of floodplain	> 4,500	5.6	2.3	4 days	Once per year
Deep inundation of floodplain	6,000	6.2	2.4	< 1 day	Once per 3-4 years

3.2.2 HYDRAULIC AND HYDROLOGICAL IMPACTS OF THE G/N SYSTEM

Water distribution according to the Joint Contractual Plan (OVIBER, 1994)

The water distribution, according to the Joint Contractual Plan (OVIBER, 1994) was specified to be:

Old Danube: 50 m^3/s

                                      200 m^3/s (considered for the vegetation season)

An increased discharge up to 200 m³/s could be released, if necessary, during the growing season (it was not specified, in which case and in which period this should be done). The amount of 50 m³/s is a guaranteed minimum discharge, which may be partially satisfied by seepage water from the reservoir.

Flood discharges exceeding 4,000 m³/s would be released at Dunakiliti into the bed of the Old Danube (for more information on flood release, see *Chapter 2.3.3*).

Hungarian branch system:

13.5-16.9 m³/s [average of 15 m³/s]
(Dec. - Feb.)
23.5-26.9 m³/s [average of 25 m³/s]
(Mar. - Nov.)

According to the Joint Contractual Plan, 13.5-16.9 m³/s from Dec.-Feb. and 23.5-26.9 m³/s from Mar.-Nov. would be supplied to the Hungarian floodplain branch system. The lower values apply after clogging of the branch system. Facilities to release up to 250 m³/s from the Dunakiliti ship lock into the side branches had been installed, but there was no agreement concerning the use of this capacity. Actually, it was agreed that any extra withdrawal of water from the reservoir exceeding the guaranteed amounts would be compensated to the other side by a corresponding reduction of the shared part of the produced energy.

Hydrological effects of the implementation of the Original Project

Mosoni Danube:

10 m³/s (Jan. - Feb.)
20 m³/s (Mar. - Dec.)

Dunakiliti-Hrušov Reservoir:

impounded volume	200 million m³
rise of water level	ca. 2 m at Bratislava
reduction in flow velocity	from ca. 2 m/s to ca. 0.30 m/s
daily water level	ca. 1 m due to peak operation
fluctuations	(see *Figure 2.5a*)

Old Danube:

· drop of water levels	2-3 m drop of water levels below the navigational low-flow level
reduction in flow velocity	from about 2 m/s to less than 1 m/s (see *Figure 2.7*)
daily water level fluctuations	during peak operation at Gabčíkovo water level fluctuations of about 4 m would occur at the conjunction with the power canal; the backwater of this sudden rise of water level would reach up to rkm 1823 in the old riverbed reversing the flow direction during the rise (see *Figure 2.5c*)
seasonal water level variations	no water level fluctuations for about 350 days per year

The Szigetköz floodplain:

Natural flow into the side branches and the floodplain would occur only for rare flood events. At 6,500-7,500 m³/s, which is a 5-10 year flood event, there would be flow in some side branches only, and at 7,500-8,500 m³/s corresponding to a 10-25 year flood almost all branches and parts of the floodplain would be inundated.

Nagymaros Reservoir:

change of water levels	+ 6 m at Nagymaros - 2 m at Sap (tailwater dredging of Gabčíkovo)
daily water level fluctuations	dependent on the peaking mode, e.g. for mean flow: 4.4 m at rkm 1801 (Sap) 2.6 m at rkm 1793 1.0 m at rkm 1768 (Komárom) (see *Figure 2.5c*)
daily fluctuations in flow velocity	from 0.3-1.6 m/s (*Table 2.4*)

Hydraulic and hydrological impacts of Variant C

Čunovo Reservoir:

The reduction in flow velocity is similar to that discussed above; to the best of our knowledge, the water level is kept at a constant level.

Water releases in the Old Danube:

> The water releases in the Old Danube *(see Plate 3.1, Volume 5)* were kept to a base level of 200-250 m^3/s in 1993 with an increase to about 350 m^3/s from May to June. In 1994 the base level of discharges was lowered to about 200 m^3/s and no increase was made in the summer (data from daily discharge measurements at gauge Rajka).

> Flood discharges above 3,000 m^3/s – corresponding to the capacity of 6 turbines at Gabčíkovo – were released in the old riverbed. For further information on flood release refer to *Chapter 2.4.4.*

Hungarian branch system:

> A lock in the connecting canal to the Mosoni Danube is used to convey some water into the Szigetköz side branch system. In 1993 the discharges varied between 2-10 m^3/s (OVIBER, 1994).

Mosoni Danube:

> A monthly average of 10-20 m^3/s were released into the Mosoni Danube until September 1994. In October 1994 the discharge was increased to about 25-35 m^3/s.

3.3 SURFACE WATER QUALITY

by László Somlyódy

3.3.1 THE NATURAL SYSTEM

The present section discusses briefly the water quality of the Danube between Bratislava and Budapest. It considers the situation in the late 1980s and early 1990s together with the trends observed and thus indicates how water quality might have evolved if the project had not been implemented (for a detailed overview of the late 1980s see Somlyódy *et al.*, 1989). It also discusses the water quality observed in 1993, and through it, some of the first impacts of Variant C. Since water quality is characterised by a number of physical, chemical, biological and other attributes which may be affected differently, the analysis will deal separately with different groups of components and types of problems.

Due to the large number of parameters for assessing the water quality, classification schemes of a few categories are used in most countries in order to quickly assess the water quality and its changes. Since there are no broadly accepted international systems – particularly not in Central Europe being in a state of strong political and economic transition – each country employs a specific

scheme which may or may not correlate. To avoid confusion, the discussion starts with the definition of class limits. Actually, due to historical reasons, three different systems will be specified as follows:

(i) The previous Hungarian classification system, valid between 1985 and the end of 1993, which consisted of three rather coarse classes (Class I indicated good quality while Class III the poorest). The basis of the classification was the 80% duration value of water quality (i.e., only 20% of all the samples taken in a year could exceed the limits of the particular class identified). It is noted that for bacteriological purposes, four classes were employed.

(ii) The new scheme, introduced 1 January, 1994, follows the recommendations of the European Union. It incorporates five categories (Classes I to V) and is based on the 90% duration level. It is finer and more stringent than the previous one.

(iii) Finally, the six-class system is presented, agreed upon by Hungary and Slovakia to evaluate the joint water quality observations (this system was actually used by several earlier COMECON countries prior to 1990).

For the purposes of effective comparison and evaluation of the water quality discussed later on, *Tables 3.2a-c* incorporate the class limits of the three systems for oxygen budget and nutrients. As can be seen, first class oxygen budget limit values of the old scheme are similar to the corresponding second class limit of the new system. With regards to the nutrient content, the earlier Class I is approximately equivalent to Class III of the new system. The two more sophisticated systems, (ii) and (iii) are very similar.

Table 3.2a: *Hungarian surface water quality classification system, valid until December 1993*

Component	Limit value		
	Class I	Class II	Class III
Oxygen budget			
Dissolved oxygen (mg l^{-1})	> 6	4	< 4
Biochemical oxygen demand BOD_5 (mg l^{-1})	< 5	10	> 10
Chemical oxygen demand COD_{KMnO_4} (mg l^{-1})	< 8	15	> 15
Chemical oxygen demand $COD_{K_2Cr_2O_7}$ (mg l^{-1})	< 25	40	> 40
Saprobity (Pantle-Buck) index	< 2.5	3.5	> 3.5
Nutrients			
Ammonium ion (mg l^{-1})	< 1	2.5	> 2.5
Nitrite ion (mg l^{-1})	< 0.1	0.3	> 0.3
Nitrate ion (mg l^{-1})	< 20	40	> 40
Ortho-phosphate ion (mg l^{-1})	< 0.3	2	> 2
Total phosphorus (mg l^{-1})	< 1	3	> 3

Table 3.2b: Hungarian surface water quality classification system valid since January, 1994

Component	Limit					Notes
	Class I	Class II	Class III	Class IV	Class V	
Oxygen budget						
Dissolved oxygen (mg l^{-1})	> 7	6	4	3	< 3	
Biochemical oxygen demand BOD (mg l^{-1})	< 4	6	10	15	> 15	
Chemical oxygen demand COD_{KMnO_4} (mg l^{-1})	< 5	8	15	20	> 20	
Chemical oxygen demand $COD_{K_2Cr_2O_7}$ (mg l^{-1})	< 12	22	40	60	> 60	
Saprobity (Pantle-Buck) index	< 1.8	2.3	2.8	3.3	> 3.3	
Nutrients						
Ammonium ion (NH$_4$-N) (mg l^{-1})	< 0.2	0.5	1.0	2.0	> 2.0	
Nitrite ion (NO$_2$-N) (mg l^{-1})	< 0.01	0.03	0.1	0.3	> 0.3	
Nitrate ion (NO$_3$-N) (mg l^{-1})	< 1	5	10	25	> 25	
Ortho-phosphate ion (PO$_4$-P) (mg l^{-1})	< 0.05	0.1	0.2	0.5	> 0.5	Surface waters not flowing into
Total phosphorus (mg l^{-1})	< 0.1	0.2	0.4	1.0	> 1.0	reservoirs or lakes.
Ortho-phosphate ion (PO$_4$-P) (mg l^{-1})	< 0.02	0.05	0.1	0.25	> 0.25	Surface waters flowing into
Total phosphorus (mg l^{-1})	< 0.04	0.1	0.2	0.5	> 0.5	reservoirs or lakes

Table 3.2c: Classification system applied in the joint Hungarian-Slovak water quality monitoring programme

Component	Limit value					
	Class I	Class II	Class III	Class IV	Class V	Class VI
Oxygen budget						
Dissolved oxygen (mg l^{-1})	> 8	6	5	4	2	< 2
Biochemical oxygen demand BOD (mg l^{-1})	< 2	4	8	15	25	> 25
Chemical oxygen demand COD_{KMnO_4} (mg l^{-1})	< 5	10	20	30	40	> 40
Chemical oxygen demand $COD_{K_2Cr_2O_7}$ (mg l^{-1})	< 15	25	50	70	100	> 100
Saprobity (Pantle-Buck) index	< 1.0	1.5	2.5	3.5	4.0	> 4.0
Nutrients						
Ammonium ion (NH_4 -N) (mg l^{-1})	< 0.1	0.2	0.5	2.0	5.0	> 5.0
Nitrite ion (NO_2-N) (mg l^{-1})	< 0.002	0.005	0.02	0.05	0.1	> 0.1
Nitrate ion (NO_3-N) (mg l^{-1})	< 1	3	5	10	20	> 20
Ortho-phosphate ion (PO_4-P) (mg l^{-1})	< 0.008	0.065	0.16	0.33	0.65	> 0.65
Total phosphorus (mg l^{-1})	< 0.016	0.13	0.33	0.65	0.98	> 0.98

3.3.1.1 Traditional chemical components

The quality of the Danube stretch considered is generally acceptable (due to the high dilution rate). For instance, in the 1980s it was evaluated as Class I and Class II according to the old classification system. It was of Class I for most of the

parameters, except for instance BOD_5, NO_2-N, NO_3-N, PO_4-P (characterising organic material and some of the nutrients), pH, oil and phenol (VITUKI, 1987). Observations performed after 1989 resulted in Class I and Class I-II for dissolved oxygen and BOD_5 respectively, according to the new Hungarian scheme (KGI, 1993). Nutrient contents were categorised as Class III-IV. System (iii) led to similar results when evaluating the 1993 observations of the joint Hungarian-Slovak monitoring programme: dissolved oxygen was of Class I, BOD_5 was of Class II (deteriorating downstream towards Budapest), P was of Class III, while N was of Class II-V (Hungarian-Slovak Boundary Water Commission, 1994).

To illustrate the average concentrations in addition to classes, at Komárom – which are typical of the Rajka-Budapest section – the 90 % duration values for the period 1986-1992 were as follows: DO (dissolved oxygen) = 8.3 mg/l, BOD_5 = 5.4 mg/l, COD_p = 7.5 mg/l, COD_d = 23 mg/l, NH_4^+ = 0.6 mg/l, NO_3^- = 14.8 mg/l, TN = 4.6 mg/l and TP = 0.4 mg/l (see KGI, 1993, for details).

The tributaries of the Danube (e.g., the Morava, Váh, Ipoly and other minor rivers, *Plates 1.1* and *1.2, Volume 5*) show a poorer water quality (VITUKI, 1987; KGI, 1993 and Hungarian-Slovak Boundary Commission, 1994). Thus, longitudinally, the Danube's quality is slightly deteriorating (again depending on the particular component considered). Due to a slow mixing rate, there are also transverse variations for many water quality parameters: the lower quality close to the left side bank shows the impact of the larger tributaries to the same side.

Trend analyses, based on data of the regular monitoring programme for the period 1976-1985, showed moderate changes (VITUKI, 1987). Generally, BOD_5, NO_3-N, PO_4-P, specific conductivity and total dissolved solids slightly increased, while DO and COD improved. Evaluation of trends for the period 1986-1992 showed significant improvements primarily due to the introduction of wastewater treatment and a reduction of industrial emissions in the upstream catchment area (also influencing heavy metals – see later) (KGI, 1993). Accordingly, BOD_5, COD, ammonia and orthophosphate concentrations improved by 4-7%/yr (average values for the Rajka-Budapest stretch), while other parameters did not change significantly (KGI, 1993).

The quality of the right side tributaries exhibited larger variations prior to the mid 1980s. The trend of deterioration could reach 10%/yr. These negative trends appear to have decreased recently at several tributaries (for details see KGI, 1993 and Csanády *et al.*, 1994).

Longer term historical changes up to the 1980s can be evaluated, for example, by comparing the minimum and maximum values of measurements performed by Liepolt in 1960 at Rajka (Liepolt, 1965) with the corresponding values of the regular monitoring programme for the period 1981-1985, for each component (VITUKI, 1987). The drastic increase in most of the parameters (see *Table 3.3*) is apparent. Particularly striking is the change in the two most important nutrient

forms, NO_3-N and PO_4-P. The latter demonstrates an order of magnitude increase (as noted before, the current trend has slightly changed but nevertheless does not influence the excess supply of nutrients, crucial from the viewpoint of eutrophication (discussed in *Chapter 3.3.1.2*)).

Trends in water quality are also reflected by increasing seasonal variability. Due to growing eutrophication and associated algae activity (see *Chapter 3.3.1.2*) the diurnal fluctuation of dissolved oxygen has been increasing significantly in the vegetation period and oversaturation can frequently be observed. Simultaneously an increase in pH can be observed (for the same reason; KGI, 1993). Forms of nitrogen and ortho-phosphate also show increasing seasonal alterations (KGI, 1993). Despite this, PO_4-P remains permanently in abundance.

Table 3.3: Changes in water quality on the Danube at Rajka
(Liepolt, 1965 and VITUKI, 1987)

Component	Dimension	1960 (Liepolt, 1965)		1981-1985	
		Min.	Max.	Min.	Max.
Total dissolved material	$mg\ l^{-1}$	183	272	181	380
pH	-	7.5	7.9	7.3	8.9
COD_p	$mg\ l^{-1}$	4.4	9.3	3.2	15.2
BOD_5	$mg\ l^{-1}$	0.6	5.3	1.0	9.8
Total hardness	$mg\ l^{-1}$	99	126	78	143
NH_4^-	$mg\ l^{-1}$	0.12	0.40	0.10	1.70
NO_2^-	$mg\ l^{-1}$	0.03	0.10	0.04	0.26
NO_3^-	$mg\ l^{-1}$	0.6	5.0	4.4	17.0
PO_3^{4-}	$mg\ l^{-1}$	0.00	0.16	0.12	1.46

3.3.1.2 Eutrophication and hydrobiology

The increase in nutrient levels outlined earlier and the improvement of light conditions due to the sediment retention of dams constructed on the upstream Danube section led to enhanced eutrophication (between the late 1950s and the late 1970s the average suspended solids concentration was approximately halved on the Rajka-Budapest reach: Berczik, 1993; Berczik and Kiss, 1994). Actually inorganic P and N are abundant in the water and they no longer limit algal growth. This explains why, in comparison to the early 1960s, there was approximately an order of magnitude increase in algal parameters such as algal count, biomass, chlorophyll-a and others. For instance, at Göd (30 km downstream of Nagymaros),

where detailed weekly observations have been available from the late 1970s, now-adays the algal count number, the biomass and the chlorophyll-a value can reach annual peak values of 60 million ind/l, 50 mg/l and 200 mg/m^3, respectively, all indicating hypertrophic conditions (Berczik and Kiss, 1994). At the same time the seasonal dynamics have also changed. From the early 1970s, these have been characterised by the occurrence of abundant algal communities in spring and increased fluctuation in dissolved oxygen levels, influenced by photosynthesis and respiration.

The development of eutrophication was accompanied by a change in the structure of phytoplankton. In the 1960s, the algal composition was dominated by diatoms, while today it has shifted towards lake phytoplankton communities as a result of increased residence time in the upstream reservoirs. The composition of phytoplankton shows seasonal dynamics. In winter, diatoms dominate, during spring and autumn diatoms, green algae and yellow-green algae are predominant, while in summer, green algae, blue-green algae and Flagellates are the most common (Hungarian-Slovak Boundary Water Commission, 1994 and KGI, 1993). The zooplankton biomass correlates with the algae biomass; its composition is also typical for slow flowing, eutrophic waters (Hungarian-Slovak Boundary Water Commission, 1994).

Longitudinal changes in algal biomass along the river are also significant. Under low water conditions the chlorophyll-a concentration at Göd can be 50-100% higher than at Rajka. It is noted that for the period 1977-1986 the mean chlorophyll-a value at Baja was approximately double the value at Rajka (see *Chapter 3.3.2.3*). This increase is primarily due to the travel time of 3-4 days under low flow between Rajka and Baja (which suggests significant biomass increase for the planned Dunakiliti Reservoir having a comparable mean residence time; Berczik, 1993).

Parameters related to eutrophication exhibit changes on different time scales (such as a day, a season, a year, a decade or decades). Up until now, year to year alterations have not yet been touched upon. They should be primarily interpreted in terms of the annual peak biomass. It can be readily demonstrated that given the present excess supply of nutrients, the maximum value depends basically on the coincidence of low flow conditions with warm, sunny days (high temperature and solar radiation). For instance, a flood – quickly reducing the residence time within a given river stretch and increasing turbidity – almost immediately collapses an algal bloom otherwise under development. Thus, the year-to-year changes strongly depend on the combined variability of meteorology and the hydrologic regime. Accordingly, the scatter is high in the peak chlorophyll-a values, and for instance, between 1977 and 1986 it varied between 70 mg/m^3 and 196 mg/m^3 at Rajka.

The conditions in the Szigetköz side-arm system, the total length of which is several times that of the main river and within which there is a large diversity in biotic and abiotic factors and hence also in life conditions (Berczik, 1993), very much depends on their water supply. Prior to the diversion of the Danube, the side-arm system was characterised by an intensive water exchange above 1,800 m^3/s

Danube flow from the total length of the associated main river. The duration of such exchange periods in a year – depending on the hydrologic regime and floods – was about 35-40 days (KGI, 1993).

As long as there is a supply to side-arms, circumstances in terms of dissolved oxygen and algal growth are similar to that of the Danube (with the difference that the residence time is usually higher). As far as the composition of phytoplankton is considered, the report of the Hungarian-Slovak Boundary Water Commission, 1994, is referred to. If inflow stops and the side-arms become disconnected, they start to behave more as lakes or ponds (their residence time can increase to several months since they are separated from the main stem for about 180 days in a year) and chlorophyll-a values close to 800-1,000 mg/m^3 can be observed (Berczik, 1993). All the changes depend very much on morphology, bed volume of individual side-arms and the water regime and thus the mosaic-like behaviour is one of the major attributes of the Szigetköz (Horváth and László, 1994). Dead arms also belong to this mosaic of waterbodies, and are characterised by phytoplankton and zooplankon communities typical of stagnant waters (KGI, 1993). The macro-zoobenthos incorporates among others rare species, atypical of the rest of the Szigetköz.

The composition of zooplankton (see Hungarian-Slovak Boundary Water Commission, 1994, for details) and fish populations depend on the hydrologic regime and the connection of the side-arm system to the main river. Their composition is characteristic of moderately polluted surface waters (Berczik, 1993). Observed changes are primarily due to eutrophication, discussed above.

The Mosoni Danube is generally of poorer quality than the main river (Hungarian-Slovak Boundary Water Commission, 1994). Downstream it is strongly impacted by the wastewater of Győr and possible backwater effects of the Danube.

The organic pollution of a river and heterotrophic bacteria decomposing in it is characterised by the so-called Pantle-Buck saprobic index which is in the ß-mesosaprobic, ß-α mesosaprobic range for the Danube stretch in question (Berczik, 1993). At the upstream section it corresponds to Class III of the new evaluation scheme outlined in *Table 3.2b*, while at Budapest it is of Class IV (KGI, 1993 and Hungarian-Slovak Boundary Water Commission, 1994).

3.3.1.3 Bacteriological water quality

Waters used for swimming should not contain infecting micro-organisms, pathogenic bacteria, fungi, parasites, their eggs etc. All these attributes are incorporated into the bacteriological water quality assessment system, characterised by nine parameters (see *Chapter 3.3.1*). Evaluations of the mid 1970s showed a Class II-III quality (WHO-VITUKI, 1976 and Deák, 1977). In the late 1980s (KVM, 1988) the entire Danube stretch upstream to Budapest belonged to Classes III and IV, i.e. the river – due to the discharge of untreated wastewater – was not suitable for bathing

(Class II is required for resorts used for bathing purposes). Recent studies report a categorisation in the Classes IV-V according to the new system (KGI, 1993 and Hungarian-Slovak Boundary Water Commission, 1994).

3.3.1.4 Micropollutants

The first heavy metal observations were performed in 1974 at Szob (WHO-VITUKI, 1976). Later several systematic longitudinal profile measurements covering Hg, Cd and Pb were made covering the entire Hungarian Danube stretch (VITUKI, 1981). The average mercury and lead concentrations were below the drinking water standards (used for comparison), while the maximum values sometimes exceeded the permitted values. For Cd, average values were significantly below the standard, while the peak concentrations exceeded it (VITUKI, 1981).

Under the framework of the joint Hungarian-Slovak water quality monitoring programme eight components are investigated. In 1993 all metals – except mercury – belonged to Class I of the accepted evaluation scheme outlined earlier in the Rajka-Medve section (and to Class I-II between Komárom and Budapest; see KGI, 1993 and Hungarian-Slovak Boundary Water Commission, 1994, for details). For Hg a few higher values were monitored between Rajka and Medve resulting in a classification in categories III-V (Hungarian-Slovak Boundary Water Commission, 1994). The impact of accidental pollution is suspected in this respect. Another reason could be the inadequacy of the monitoring programme. The sampling frequency was much smaller than usual for traditional components, which is associated with the little knowledge available on the dynamics of Hg. Thus the degree to which these observations are representative is questionable.

As far as organic micropollutants are concerned, more than ten compounds (such as lindane, atrazine, aldrin, dieldrin, DDT, PCBs) were investigated in the upper stretch of the Hungarian Danube and upstream of the capital. The latter were considered as the most important results from the viewpoint of drinking water supply and toxic impacts.

Atrazine is a typical pesticide present in the Danube water owing to its widespread use in agriculture. Higher concentrations occur during application periods and intensive runoff events (non-point source impact). Sometimes highly fluctuating concentrations of volatile chlorinated solvents are observed in the Danube. However, even in the case of the above mentioned organic micropollutants, the characteristic concentrations were below the limits considered hazardous for aquatic life or drinking water.

Most of the other organic micropollutants were not detectable or their concentration was much smaller than the corresponding standard (KVM, 1988; Csanády, 1993; Horváth and László, 1994 and Hungarian-Slovak Boundary Water Commission, 1994). Thus, they do not form a problem at present.

3.3.1.5 Sediment contamination

The first sediment heavy metal measurement (from the top 5 cm layer) was performed in 1977 which was followed by a number of other studies. For the purpose of the evaluation the monitored sediment concentration was compared to natural ("unpolluted") background levels and to soil standards used in agriculture (these specify values still tolerable by plants, see below). The average sediment heavy metal concentrations did not exceed the standards, however the maximum values were permanently larger than the limit (except for Cu). In 1987 observations were made in side-arms of the Szigetköz and in the vicinity of bank filtered wells within the impact area of the GNBS. The smallest values were obtained in the upper reach of the Danube, while the highest values were found in the middle stretch, between Tát and Göd (VITUKI, 1988b).

From among the organic micropollutants the highly resistant compounds tend to be accumulated in the sediment, that is why it contains chlorinated hydrocarbon type pesticides, polyaromatic hydrocarbons and oil. The evaluation of sediment quality has not yet been standardised (this is the reason why soil standards are used). Recent efforts focus on the application of internationally accepted methods, among others in the frame of the Cousteau programme (Equipe Cousteau, 1993). The same study showed that the contamination of the Danube sediment for the organic micropollutants was inferior to those measured in some comparative western rivers (this statement applies to the entire Danube characterised by 52 sampling points of which 6 were located between Bratislava and Budapest). In contrast, heavy metals in the sediment span a wide range of concentrations "which overlaps those of "uncontaminated' and 'polluted' rivers" used for comparison (Equipe Cousteau, 1993).

The contamination of sediment largely depends on flow conditions and particle size distribution. In stagnant zones where accumulation is fast, sediment core sample analyses showed that the thickness of the contaminated layer can be several metre (VITUKI, 1983). Detailed assessment revealed that for all the pollutants the smallest fraction (< 90 µm) had the highest concentration. Here even the average metal concentrations exceeded the standard (VITUKI, 1988b). Unfortunately, our available knowledge is inadequate for the understanding of the transport and accumulation of fine sediment fractions and associated micropollutants, as well as their possible harmful effects.

3.3.2 IMPACTS OF G/N SYSTEM ON SURFACE WATER QUALITY

The construction of a barrage can influence all the different aspects of water quality discussed above in many different ways, through a number of complicated processes which can be interrelated. One of the most critical issues in relation to the GNBS was that a comprehensive impact assessment on water quality was not prepared (the 1985 EIA hardly incorporated any analysis on water quality). This

situation would have been acceptable in the early or mid 1970s when possible negative impacts of damming on water quality were not yet widely recognised, however for the late 1980s the presence of such an evaluation – by using models and other methodologies to compare future impacts of alternative solutions of various projects – was considered essential in the developed world. Standards of assessment methodologies have developed tremendously during the past decade or so, and the procedure to be followed, virtually on a compulsory basis, is becoming increasingly elaborate (see *Chapter 7*). It suffices to refer to the Environmental Assessment Sourcebook of the World Bank and its sections dealing with water, water quality, dams and reservoirs (World Bank, 1991).

3.3.2.1 Uncertainty in understanding and lack of an impact assessment

Damming influences surface water quality primarily by increasing the sedimentation and residence time. In addition to these, peak operation mode has a further, largely unexplored impact. Most of these impacts seem to lead to negative changes, although their order of magnitudes are hard to quantify (given the present level of knowledge and studies performed). There can also be positive water quality changes among the many sided and interrelated effects.

For instance, growing residence time leads to increased organic material removal and associated dissolved oxygen concentration reduction. In turn, the latter can be compensated by enhanced oxygen re-aeration due to the increased surface area, wind impact and the effect of turbines. In fact for the Danube, changes in the dissolved oxygen budget in the main waterbody seem to be insignificant (see VITUKI, 1978 also for the simplifying assumptions employed). At the same time, increased residence time together with improved light conditions due to enhanced sedimentation of suspended solids (which also leads to the deposition of contaminants attached to the particles) intensifies algal production leading to the production of organic material inside the reservoir or reservoirs (known as internal or secondary organic material load) and associated dissolved oxygen changes.

In turn however, barrage construction usually has a positive effect on bacteriological water quality (see Csanády, 1993) – depending on concentration and other conditions.

In a slightly broader sense, damming can influence sediment transport (including sedimentation and erosion), eutrophication, organic material contamination, dissolved oxygen conditions close to the bottom due to the decomposition of organic material deposited, clogging and the impact on groundwater quality (i.e., by the appearance of iron, manganese and ammonia under anaerobic conditions; see *Chapter 3.5.2.3*). The transport of fine sediment, crucial from the viewpoint of the fate of micropollutants (see *Chapter 3.3.1.5*), the transversal distribution of deposition/erosion in cross sections at reaches with differing flow conditions and various interface processes outlined above are hard to quantify on the basis of

information and assessment available for the GNBS and they cause significant scientific uncertainty. The impact of peak operation leads to an additional element of the uncertainty.

The issue is further complicated by different time scales of impacts. For instance, changes in the dissolved oxygen budget (in the waterbody) appear relatively quickly. The development of eutrophication in a freshly constructed reservoir and its observation, taking into account year-to-year fluctuations, may take several years. Impacts associated with interface processes (deposition, erosion, clogging, influence on groundwater, etc.) may appear even on a longer time scale (i.e., a decade or more).

The lack of analyses and the level of uncertainty related to the above complex potential water quality changes, are illustrated subsequently by two examples – stressing that a detailed systematic evaluation is missing even today. Due to temporal effects and ongoing changes, a comprehensive assessment may not be possible within a short period of time: this raises important questions as to the possibilities of operational corrective measures.

3.3.2.2 Impact of the peak operation on the dissolved oxygen budget of the Mosoni Danube

The impact of the GNBS project on the oxygen budget of the main Danube was analysed using the traditional Streeter-Phelps model in 1978 (VITUKI, 1978) which in fact is too limited for the given problem since the impacts of the N and P cycles were neglected. The conclusions were twofold: due to reasons outlined in the previous section, BOD will improve by 0.5-1.0 mg/l and at the same time as a penalty, dissolved oxygen will somewhat deteriorate, but it will remain larger than 7 mg/l under summer low flow conditions which still indicates a good quality. The effect of peak operation was neglected (together with several other factors) which is probably a reasonable assumption for the main river, however not for the Mosoni Danube. This recognition led to an order of magnitude type of analysis in 1989 (Somlyódy et al., 1989) which is outlined below.

The Mosoni Danube is heavily loaded by the raw wastewater of the town of Gyôr (about 80,000 m^3/d) which causes an approximate 2 mg/l dissolved oxygen reduction in the Mosoni Danube prior to the junction to the main river (under low flow conditions for both rivers). The operation of the GNBS would seemingly improve the situation since the daily average dilution rate increases according to the plan. However, the designed peak operation would induce a tidal-like back-and-forth motion resulting in a significant increase in the local travel (or residence) time.

Detailed studies show that three periods of different flow conditions will develop repeatedly each day: a downstream flow of about 8 hours duration, a reversed flow of approximately 6 hours and finally again a downstream flow of 10 hours. On the

basis of hydrodynamic model computations absolute values of the velocity range between 0.3 m/s and 0.5 m/s depending on the flow regime and the type of the operation. Thus, when reversed flow develops, pollution is transported upstream while organic material removal and dissolved oxygen consumption proceeds, which then continues after the change in flow direction, particularly when the river water already poor in dissolved oxygen again meets the wastewater discharge.

The phenomenon was handled as a first estimate by the classical Streeter-Phelps equations which should be incorporated into a set of longitudinal dispersion equations (using velocities as inputs from the hydrodynamic model). These can be solved numerically (for details see Somlyódy *et al.*, 1989). Results are to be seen in *Figure 3.2a*. It is apparent from the figure that the dissolved oxygen reduction is larger than under the present conditions even if biological treatment is introduced, and at the mouth of the Mosoni Danube, dissolved oxygen values below 4 mg/l can develop.
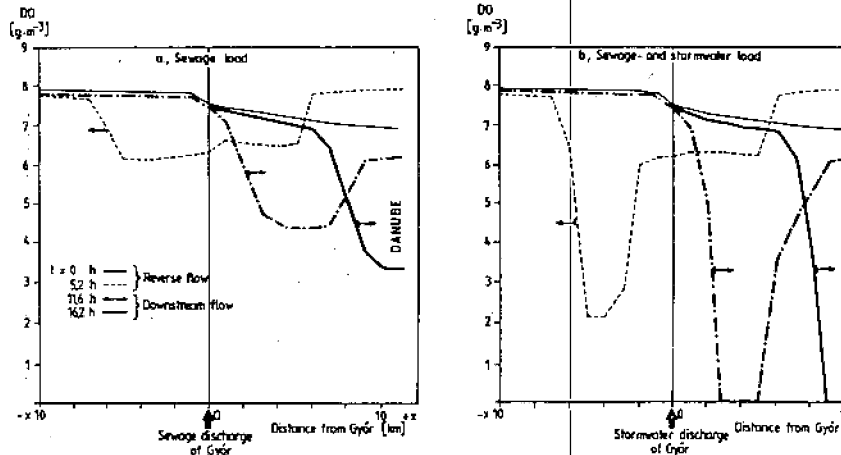
Figure 3.2a and b: *Changes of dissolved oxygen levels in the Mosoni-Danube due to peak operation of the Gabčikovo-Nagymaros river barrage system (after Somlyódy, 1991)*

More striking is the situation under stormwater conditions: a rainfall event occurring once a year – an assumption, typically used for design purposes – can lead to complete oxygen depletion in the Mosoni-Danube (see *Figure 3.2b*). Thus, wastewater treatment alone does not lead to a satisfactory solution. In addition, the construction of a detention basin is needed or the stormwater should be diverted to the main Danube where the rate of dilution is much larger than in the Mosoni branch. Unfortunately, however, this issue was not raised at all, clearly indicating that water quality impacts were ignored in the course of planning and possible prevention or mitigation measures were not considered.

3.3.2.3 Eutrophication

The impact of the GNBS on eutrophication can be evaluated by nutrient cycling models well known from literature which among others describe changes in the biomass due to growth, death, sedimentation and convective transport. The growth rate is a complicated, non-linear function of the temperature, solar radiation, suspended solids concentration and the biomass itself (called the self-shading effect). The death rate depends primarily on the temperature.

The transport term is a function of the flow influencing the residence time. Due to storage, it increases in the Dunakiliti Reservoir by a factor of 4-5 compared to the pre-dam situation. The consideration of convection necessitates the incorporation of reaction terms into transport equations which use velocities and geometric parameters as inputs from a hydraulic model. Since residence times are significantly higher in the floodplain regions of the Dunakiliti Reservoir than in the main channel (and other parameters such as the thickness of the photic zone relative to the water depth are also different), the two-dimensional effects should be accounted for. Due to its different nature, the Nagymaros Reservoir can be well approximated by a one-dimensional treatment.

It is noted that the study of Somlyódy et al., 1989, used several assumptions which then were refined by Bakonyi, 1994. In addition, the first effort considered only critical summer conditions, while the recent, more comprehensive study simulates a year or several years.

During low flow conditions (approximately 1,000 m^3/s) the theoretical, average value of the residence time can reach about 70 hours in the Dunakiliti Reservoir (associated with a mean velocity of about 0.05 m/s), while under higher flows (4,000 m^3/s) it would be less than 20 hours (in the 95 km long Nagymaros Reservoir of throughflow character the increase of the residence time would be smaller than in the upper one (at Dunakiliti) and velocities would remain in the domain 0.35-1.4 m/s depending on the flow).

As noted earlier, a sudden change from low water to high water conditions due to floods leads to a fast reduction in the residence time which can quickly counteract the impact of algal growth and can flush out blooms within a day or so, a well known phenomenon. The impact of variability of flow and meteorological factors, and seasonal changes are well reflected by *Figure 3.3* which illustrates chlorophyll-a changes in the Rajka cross-section of the Danube. The figure shows at the same time that the above algae model acceptably describes the observed changes (for the computation of the Rajka section the upstream river system was replaced by an equivalent river stretch utilising the presence of excess nutrient supply) and thus it can be used for the analysis of future changes of different alternatives in a relative sense. The year 1976 was used for calibration while 1986 was employed for validation.
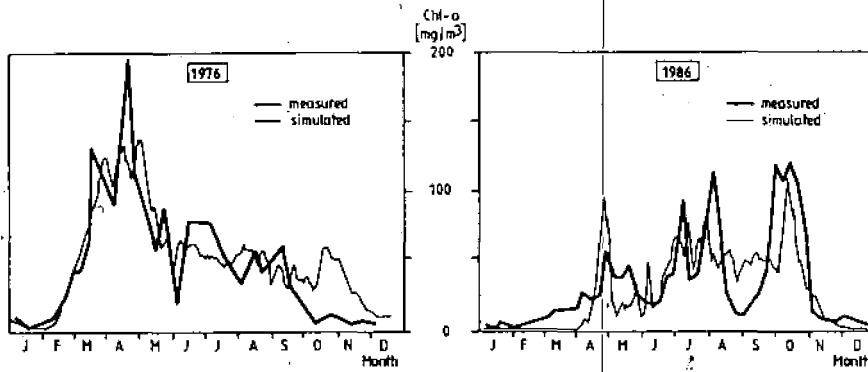
Figure 3.3:Computed and measured chlorophyll-a concentrations: Danube at Rajka (Somlyódy, 1991)

The coupled hydrodynamic-water quality model covering the entire Hungarian Danube stretch gave similarly good agreements between simulations and observations. For the model, data of the Rajka cross-section were used as upper boundary conditions, and flow and chlorophyll-a at Baja were computed. The unsteady flow model was calibrated and validated as a first step (see *Figure 3.4*). Calibration and validation results of the eutrophication model are shown in *Figure 3.5* (Bakonyi *et al.*, 1991; Somlyódy and Varis, 1993 and Bakonyi, 1994).

Model computations showed that the increase of algal biomass in the main channel of the reservoir is relatively small, about 10% since the residence time here changes only by a small extent. The situation is different in floodplain regions as the residence time can be much longer than in the main channel. Also the water depth is significantly less and thus the relative photic zone is much thicker than in the main river. As a result of all these factors, chlorophyll-a can increase from the assumed 40 mg/m^3 at the inlet of the reservoir to more than 200 mg/m^3. At the outlet the chlorophyll-a concentration is about 100 mg/m^3, i.e., as an impact of the reservoir the biomass can approximately double. These effects would be further amplified by the Nagymaros Reservoir which would induce some additional algal growth (it would be significantly smaller than for the upstream reservoir not only due to the smaller increase in the residence time but also due to the greater average depth and the smaller relative thickness of the associated photic zone).

Unfortunately the uncertainty of the estimate of the impact of the Dunakiliti Reservoir is relatively high. This was studied in the frame of a sensitivity and a Monte Carlo analysis framework (Somlyódy *et al.*, 1989) which resulted in 30% standard deviation of the outflow chlorophyll-a concentration estimate (and higher values for the floodplain regions).
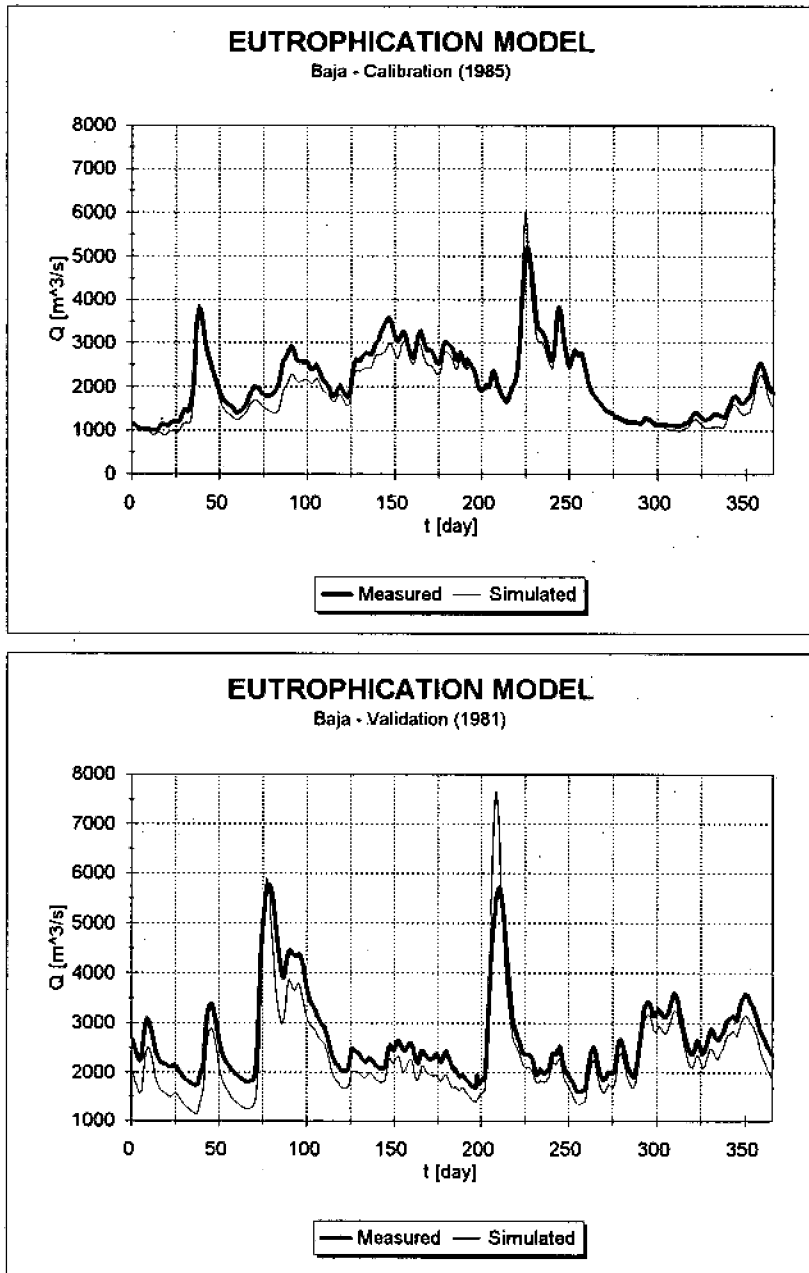
Figure 3.4: *Unsteady hydrodynamic model calibration (1985) and validation (1981) Flow at Baja*
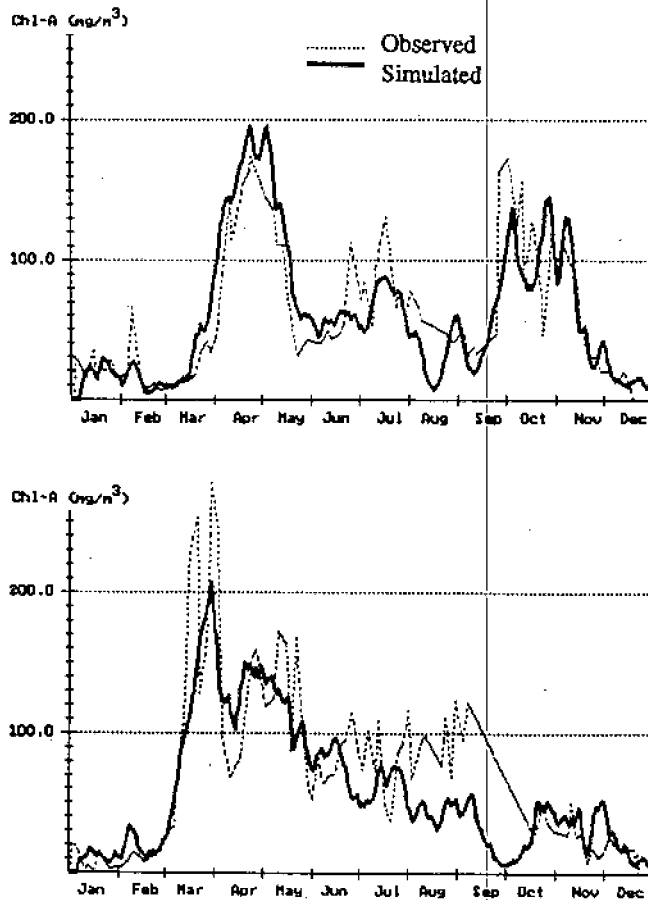
Figure 3.5: Calibration and validation of the eutrophication model. Observed and simulated chlorophyll-a content at Baja (after Somlyódy and Varis, 1993)

As noted before the above estimate was obtained for summer conditions by assuming a fixed inflow chlorophyll-a concentration. Full-year dynamic simulations were performed by Bakonyi, 1994 for the period 1977-1986 to investigate the impacts of the Original Project and their variability. The increase in the annual biomass as an impact of the Dunakiliti Reservoir (expressed in terms of chlorophyll-a) ranged between 45% and 90%, reflecting also the role of the hydrologic regime and meteorological condition (*Figure 3.6*). The error of this estimate is similar to that outlined before, again primarily due to the role of the floodplain (Bakonyi, 1994).

The estimated impact of the Dunakiliti Reservoir, taken as a whole, is close to the chlorophyll-a increase observed between Rajka and Baja (see *Chapter 3.3.1.2*). The additional percentage increase of the chlorophyll-a concentration at Baja is

anticipated to be smaller than outlined above, primarily due to the discharge of the largely untreated wastewater of Budapest which from the point of view of algal growth, leads to less favourable light conditions downstream of the capital (Csanády, 1993 and Bakonyi, 1994).

EUTROPHICATION MODEL
Increase of Algae Biomass at Szap
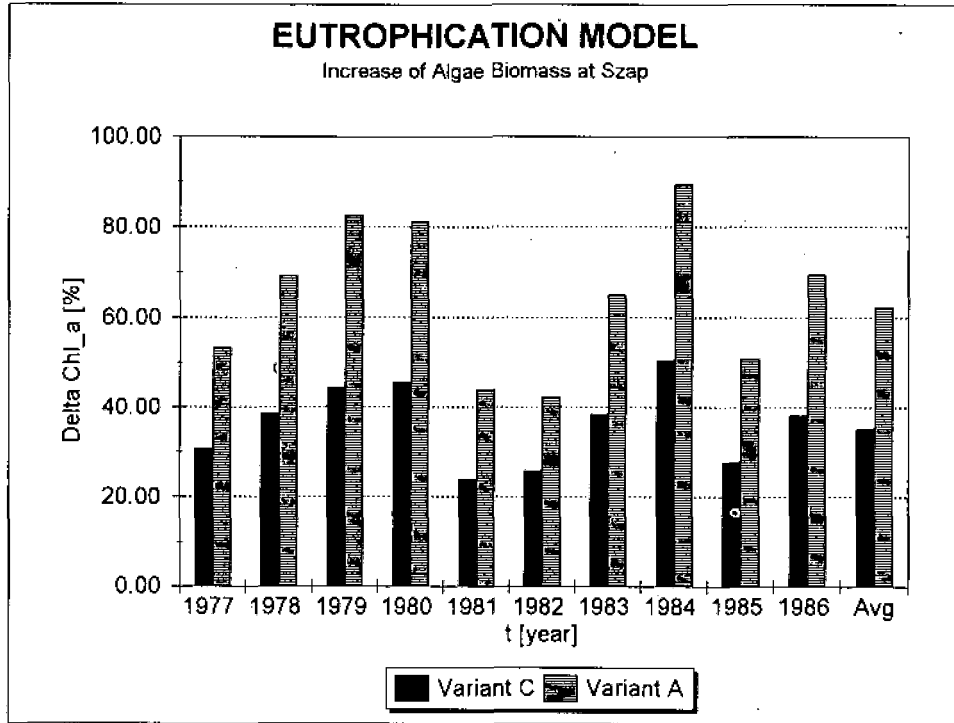
Figure 3.6: Change in the chlorophyll-a content at Sap due to the Original Project and Variant C (assuming historical records of hydrology and meteorology to demonstrate variability)

It is noted that the impact of peak operation and episodic wind events on algal growth was neglected in the scope of all the studies performed until now. Both phenomena can increase sediment re-suspension and reduce light penetration which would tend to diminish the above effect.

The increased biomass can require the modification of the technology of the surface waterworks of Budapest which is used primarily during the summer period. Methods of upgrading are known, (some changes were already performed, Csanády, 1993); however, they are expensive. It is also noted that due to the drop in water consumption during the past four years, this intake plays a somewhat more reduced role than before.

Increased biomass causes an internal load of organic material which — unlike organic material of sewage origin — increases downstream in the vegetation period

when algal growth exceeds mortality. Ironically, in the vegetation period the BOD_5 increase stemming from algal growth can be equivalent to (or larger than) the total external organic material load between Rajka and Budapest, and thus BOD_5 levels would not improve even if all the wastewater were treated biologically. Clearly, the solution of the eutrophication problem of the Danube stretch considered does not depend on wastewater treatment along the given reach, but it would require a co-ordinated international programme to reduce the phosphorus in the entire upstream basin.

3.3.3 POTENTIAL IMPACTS OF VARIANT C ON WATER QUALITY

Very few water quality studies are available on the impact of Variant C. The brief evaluation given here is based on Csanády (1993), Horváth and László (1994) and Bakonyi (1994).

3.3.3.1 Eutrophication

Most of the impacts are as discussed for the Original Project, but from the viewpoint of eutrophication, Variant C should be considered less unfavourable than Variant A: due to the reduced volume the residence time increases to a lesser extent and thus the increase in algal biomass is also smaller. This behaviour is clearly reflected by model computations (Bakonyi, 1994); using historical data for 1977-1986 – as for the analysis of the effect of the Dunakiliti Reservoir – the annual average increase in the biomass at Sap ranges between 25% and 50% (see *Figure 3.5*). This is smaller than the natural variability at Rajka (the mean of yearly average chlorophyll-a concentrations is about 30 mg/m^3 for the same period of time, while the minimum and maximum values are 16 mg/m^3 and 44 mg/m^3 respectively, i.e., ±50% around the mean). The observations of 1993 – data for 1994 were not yet available when the present document was prepared – are in harmony with the above findings (Csanády, 1993): on the basis of this single year no impact can be observed. Knowing the natural variability of chlorophyll-a and the estimated impact of Variant C, probably more than a decade is needed to detect the trend with statistically acceptable accuracy.

3.3.3.2 Other impacts on the main river quality

As a result of diverting the Danube in 1992 and increased sedimentation in the new reservoir, the suspended solids concentration dropped markedly in 1993: the annual average at Medve was 24 mg/l in comparison to 48, 47, 36 and 36 mg/l monitored in the course of the preceding four years (1989-1992; Horváth and László, 1994). It is noted that the reduction is higher in the variance and extreme values characterising fluctuations within the year. Simultaneously, the chemical and biological quality also showed slight changes: COD_p and COD_d mean values

were somewhat reduced (due to increased sedimentation and organic material removal in the reservoir). Dissolved oxygen also seems to alter (reasons discussed earlier) which is shown primarily by the smaller minimum value detected (6.2 mg/l) in comparison to previous years (7.6, 6.8, 7.4 and 7.4 mg/l in the same sequence as before). Certainly, experiences of a single year can offer the first signs of changes, but they are not satisfactory for drawing stronger conclusions.

Bacteriological quality for 1993 suggests an improvement (Csanády, 1993) which – as outlined earlier – is a likely impact of the operation of the Čunovo Reservoir. However, the recent reduction in industrial emissions referred to several times may also have contributed to this. In spite of this improvement valid for the entire Danube stretch upstream to Budapest water is still far from being suitable for swimming.

Data available for 1994 do not support the improving trend in bacteriological quality which could be suspected from the 1993 observations (Csanády *et al.*, 1994). Our earlier remark is repeated once more: conclusions on water quality impacts can not be drawn on the basis of the measurements of a single year.

3.3.3.3 Impacts on water quality of the Szigetköz and the Mosoni Danube

The diversion of the Danube drastically affected water supply to the side-arm system (*Chapter 3.2.2*). In the past, these laterals carried fresh water during split conveyance of flood flows, but were drained rapidly as the river stages dropped. During periods between floods, water remained in the deeper side-arms alone, or these were recharged with groundwater seeping towards the main stream. After the diversion, as an attempt to feed the side-arms, a maximum flow of 10-12 m^3/s was introduced in the second half of summer in 1993 into the flood bed recharging system from the flow released to the Mosoni Danube. The recharging system impacted the side-arms along the lower Szigetköz, over a length of about 20 km (Horváth and László, 1994).

Observations revealed that the water quality of the five side-arm systems on the Hungarian side responded perceptibly to the changes of water supply. Without going into detail (see Horváth and László, 1994), a basic difference was induced in the nature and type of water supply. The irregular, dynamic water supply along the entire Szigetköz (driven by the hydrologic regime) was replaced by a more or less steady limited flow supply only from upstream changing drastically connections and disconnections, as well as their spatial and temporal patterns. The mosaic-like nature of the system has changed which is leading to a basically different pattern of water quality than in the past. This is again an issue which requires several years of observations before we can see the total impact.

The water supply of the Mosoni Danube also changed as a result of the diversion. The impacts in 1993 appeared primarily in dissolved oxygen conditions due to

upstream eutrophication, the occasionally poor quality of water released by the Slovak side and hydrometeorological conditions. These resulted jointly in periods of low dissolved oxygen level and fish mortalities in August.

3.4 GROUNDWATER

by Howard Wheater

3.4.1 THE NATURAL SYSTEM

3.4.1.1 The Szigetköz and Adjacent Areas

The geological development of the Little Danube Plain has been intimately linked with the morphological development of the Danube, leading to the formation of an extensive Quaternary alluvial aquifer (*Plates 3.2* and *3.3, Volume 5*). The Hungarian aquifer in the Szigetköz is estimated to have a volume of some 21.8 km^3 (Erdélyi, 1994) and is overlain by a spatially variable upper layer of fine soil, from 0-5 m in depth (*Plate 3.4, Volume 5*) and underlain by a sandy-clayey complex, which holds thermal waters at depth. The pattern of recharge is indicated by regional groundwater levels (*Plate 3.5, Volume 5*) and stable isotope tracer analysis (*Figure 3.7*). The Danube has been the dominant recharge source of the Szigetköz and Žitný Ostrov aquifers; water originating from the Danube has been found at depths of several hundred metre in the Szigetköz, and beyond the Mosoni Danube. In contrast, rainfall recharge is small (for this part of Hungary, potential evapotranspiration exceeds rainfall by 30% (Petrasovits, 1988)). However, beyond the Mosoni Danube, other recharge sources become progressively more important.

Knowledge of the aquifer has developed significantly during the 1980s and 1990s (Liebe, 1994). In particular the spatial complexity has become increasingly apparent, and more information has become available on the behaviour of the aquifer at depth. What was originally seen as a homogenous system has been found to be strongly anisotropic (first estimates indicated a 4:1 ratio of horizontal:vertical permeability; this has been revised to up to 30:1) and spatially heterogeneous, reflecting the complex and changing pattern of alluvial deposition. Flow velocities are highest at 50-100 m depth. The horizontal hydraulic conductivity varies from as little as 20 m/d in the upper aquifer to up to 300 m/d at depth. This indicates flow velocities in the range 200-300 m/year, consistent with the stable isotope results.

Hydraulic connection with the main Danube channel occurs throughout the Rajka-Gönyü reach, and prior to construction of the Variant C reservoir, Danube flows determined the groundwater levels throughout the Szigetköz and beyond. *Plate 3.5 (Volume 5)*, discussed above, presents the average water-table elevations in 1990 (which are representative of the later 1980s response) from which approximate flow directions can be inferred. In fact the response is more complex; under high

Danube flow conditions the predominant groundwater flow direction changes from south-east to south, reflecting the importance of high flow recharge to the Sziget-köz. Groundwater levels in the Szigetköz follow closely the variation in Danube water levels, but with decreasing amplitude as distance from the Danube increases. Thus adjacent to the Danube, groundwater fluctuations in excess of 2.0 m can be observed. Close to the Mosoni Danube these have reduced to 1.0 m or less.

tritium front ----- *Oxygen 18*
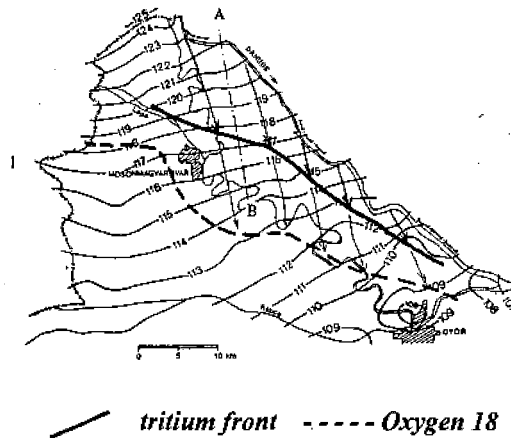
Figure 3.7a: Groundwater levels m asl.(after Liebe, 1994)
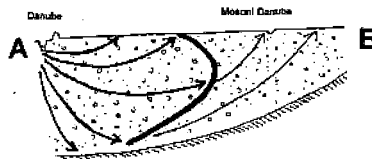
Figure 3.7b: Stable isotope analysis of tritium (after Liebe, 1994)

The depth of the water-table below the surface is of major importance for capillary moisture supply. If the water-table rises into the fine soils overlying the coarse alluvium of the aquifer, the water can rise up the soil profile by capillary action and provide an important contribution to the water use of both natural vegetation and agriculture (see *Chapter 5*).

The *average* water-table depth below ground surface is given in *Plate 3.6 (Volume 5)* for 1990 conditions. This can be compared with the thickness of the fine-grained sediment (*Plate 3.4, Volume 5*), from which it can be seen that capillary supply becomes progressively more important moving from the Upper to the Middle to the Lower Szigetköz. However, average water-tables underestimate the importance of this effect. Flood flows in the Danube characteristically occur in late spring/early summer and may be followed by late summer floods. Hence the highest groundwater levels coincide with the period of high water demand by

plants and maximum climatic stress. This provides a natural sub-irrigation which has been an essential feature of the ecology and agriculture of this area.

When considering groundwater in the Szigetköz, historical trends should be noted. The degradation of the Danube bed due to excessive gravel removal at Bratislava has been discussed extensively in *Chapter 2*. This has had the effect of reducing Danube water levels, and hence groundwater levels. The average water-table depths in the period 1956-1960 are shown in *Plate 3.7 (Volume 5)*. The average depth was very close to the surface (< 1 m) in the floodplain, generally between 2 and 3 m elsewhere in the Szigetköz, and deeper than 3 m to the south-west of the Mosoni Danube.

Historical Danube water levels in the Upper, Middle, and Lower Szigetköz are shown in *Figure 3.8*. At Rajka, mean water levels in the 1970s had decreased by 25 cm, in the 1980s by a further 45 cm, and in the early 1990s by an additional 70 cm. This was reflected in reduction of groundwater levels in the Upper Szigetköz of in excess of 1 m (*Plate 3.6* and *Plate 3.7, Volume 5*). In contrast, Danube water levels in the Middle and Lower Szigetköz remained relatively stable until the early 1990s. A recent decline at Nagybajcs is probably due to dredging for navigation, and an observed decrease in groundwater levels in the south-east is due in part to groundwater abstraction.

Historical groundwater levels are shown in *Figure 3.9* from a transect of 3 wells (indicated on *Plate 3.13, Volume 5*). The general decrease in amplitude of groundwater fluctuations with distance from the Danube is illustrated, and it can be noted that the amplitude of variations, indicated on *Plate 3.7 (Volume 5)* for 1956-60, remained largely unchanged prior to construction of Variant C.

As discussed above, the Danube is the primary source of recharge to the Szigetköz, and it is estimated from groundwater modelling (Simonffy, 1994) that average recharge from the Danube to the Hungarian floodplain was 8.1 m^3/s under average (1981-1990) conditions, and from the floodplain to the Szigetköz beyond was 5.2 m^3/s.

As already noted, the volume of the Szigetköz aquifer is estimated to be 21.8 km^3 and contains approximately 5.4 km^3 of groundwater. It is thus a unique resource of good quality water, which at present is mostly not utilised. The larger waterworks in the area are Győr, Kisbajcs-Szögye and Győrújfalu. Together with Mosonmagyaróvár, production is estimated to be 70,000 m^3/d. In addition, minor amounts are extracted by numerous small settlements. This can be compared with resource estimates of the National Water Management Masterplan (1984) of 750,000 m^3/d. However, this underestimates the additional induced yield which could be generated by bank-filtered wells. It can be seen that there is a sufficient resource to supply a major city (the same order as Budapest), and as such this is regarded as of national strategic significance.

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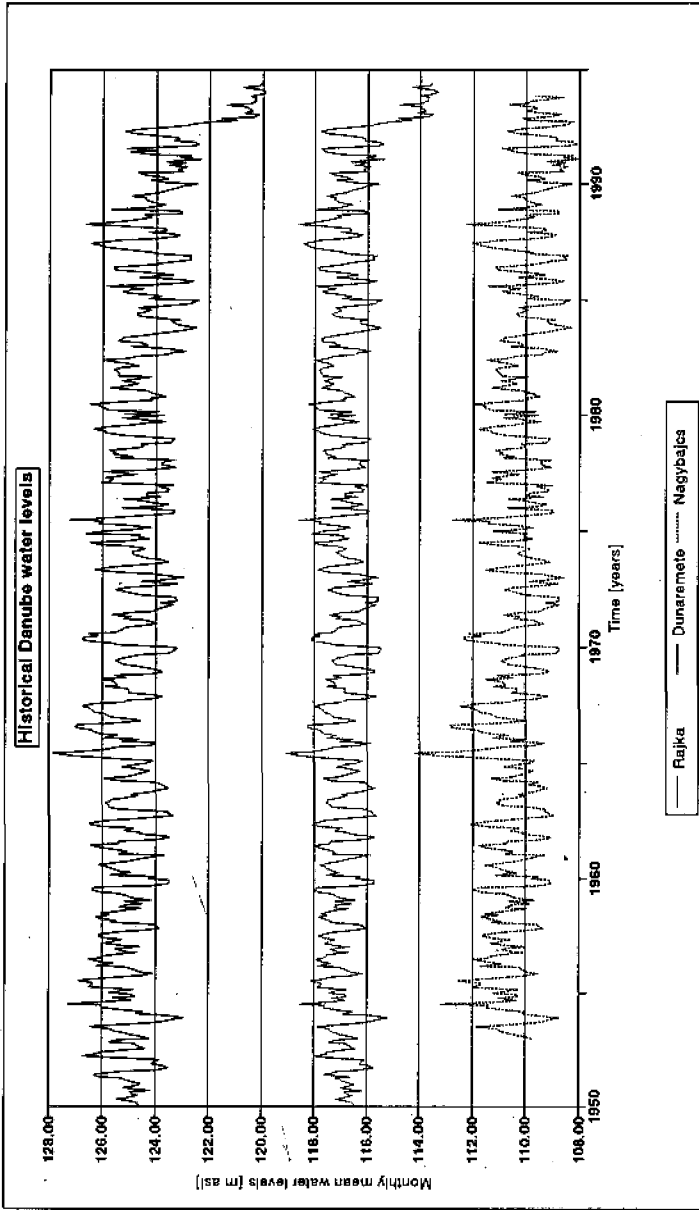
Figure 3.8: Water levels of the Danube 1950-1994 at Rajka, Dunamerete and Nagybajcs
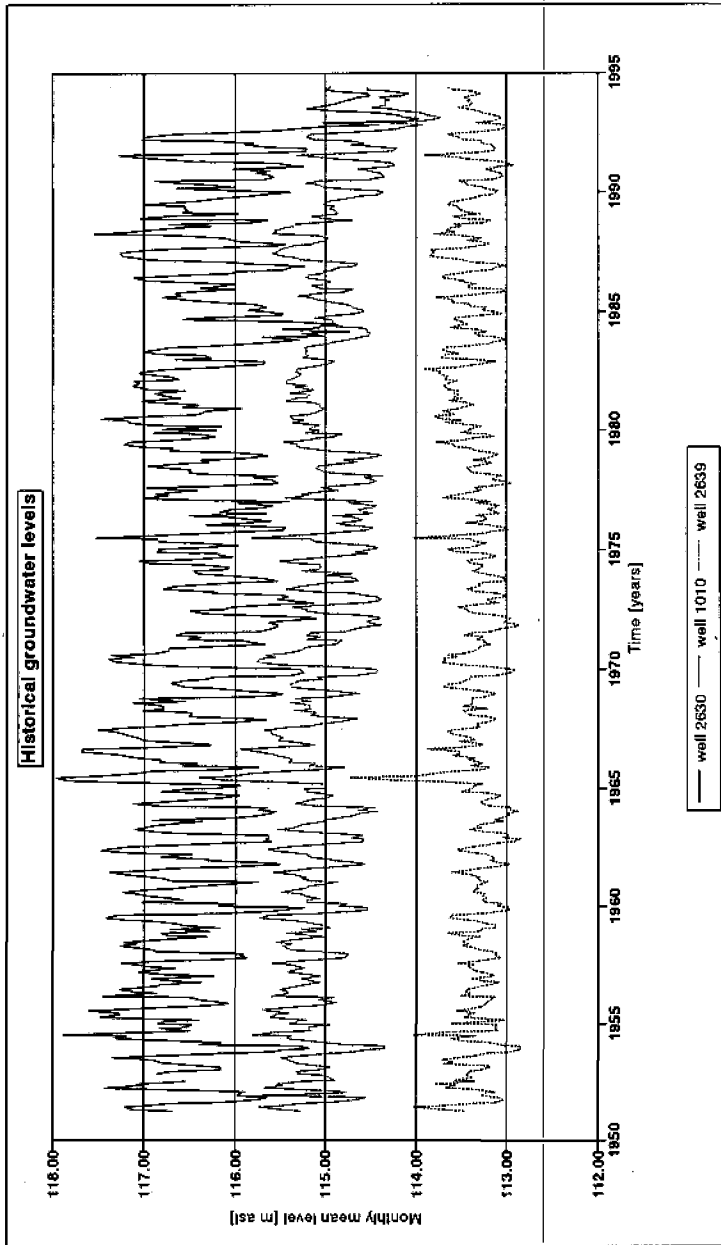
Figure 3.9: Groundwater levels from 1950-1994 at wells 2630, 1010 and 2639

3.4.1.2 Gönyü to Nagymaros

Considering the right bank of the Danube between Gönyü and Dunaalmás, the gravel aquifers adjacent to the Danube are much thinner (a few tens of metres in depth), and discontinuous. Continuous recharge from the Danube does not occur. Generally, some infiltration into the Danube takes place from off-river sources. From Nyergesujfalu towards Nagymaros, the right bank aquifer, comprising coarse clastic formations, becomes wider and deeper in the Dorog basin. Further downstream, discontinuous alluvial formations recur, on both sides of the river, with a wider and deeper formation in the Pilismarót basin.

Throughout this reach, there are important bank-filtered waterworks (*Plate 3.8, Volume 5*), and significant unused additional resources. The issues of bank-filtered water supply are considered in detail in *Chapter 3.6*, below.

There is also an inter-relationship with the karst water of the Transdanubian Mountain range which is the largest, and economically most important, karst water resource in Hungary (Lorberer, 1994). The regional erosion base of the north-east mountain range is the Danube, and thermal karst springs emerge along the river at faultlines at locations which include Dunaalmás, Esztergom and Budapest. These have a centuries old history of use for water supply and medicinal baths.

The progressive development of mining in the Transdanubian Range led to the need to pump substantial volumes of water from this karst system, and by the late 1960s, extraction exceeded natural recharge. As a result, water levels and spring discharges have decreased. Under natural conditions, the levels of the Danube influence the yield and quality of the springs and adjacent groundwaters. Following the influences of mining activity the head (i.e., potential energy) in parts of the aquifer has fallen to below Danube water levels, leading to some ingress of Danube water to the karst aquifer. These rates increased up to 1991, but following recent decreases in mining activity, have started to decline.

3.4.1.3 Nagymaros to Budapest

The alluvial aquifer between Nagymaros and Budapest is the major source of water supply for the capital. Almost all of the water supply for Budapest comes from bank-filtered wells. 64% of this water comes from the Nagymaros-Budapest reach, principally from a 10-20 m deep aquifer underlying the Szentendre island (*Plate 3.9, Volume 5*). At mean Danube flow levels, the groundwater has a depth of 10-15 m which is decreased by 2-3 m due to the depression of the wells. At low flows, a further reduction in water-table height of approximately 2 m occurs, with an associated decrease of the filter area of the channel bed.

The issues of water supply from this resource are of major national strategic importance, and are discussed in detail in *Chapter 3.6* below. However, it can be noted that bed changes, due to dredging and river training, have given rise to serious problems of loss of yield and degradation of water quality.

3.4.2 IMPACTS OF THE ORIGINAL PROJECT

3.4.2.1 The Szigetköz and adjacent areas

The construction of the Dunakiliti Reservoir is associated with a complex set of process interactions which cannot be quantified without high levels of uncertainty, and which potentially imply extremely serious adverse consequences for the Szigetköz. The concerns which existed in 1990 are fully documented by Liebe (1994).

The raising of water levels in the reservoir would have undoubtedly led to initially increased local groundwater levels. However, a significant proportion of the inflowing suspended sediment load of the Danube would have settled in the reservoir. The spatial distribution of the settled sediment is uncertain, but clogging of the bed could be expected. Extensive research was undertaken at VITUKI, including laboratory tests and large-scale field experiments, which suggested that clogging was likely to occur and to increase bed resistance to infiltration by a factor of 30 (Starosolszky, 1966, 1981). This was consistent with international experience (Darmendrail, 1986, 1988).

The Original Project envisaged a discharge of 50 m^3/s in the main Danube downstream, hence the natural pattern of groundwater recharge would have been profoundly modified. Minimal recharge would have derived from the Danube river bed in this downstream reach; initially substantial recharge would have occurred from the reservoir, but this was expected to have progressively reduced due to sedimentation. The expected effects included a radical change to the patterns of groundwater flow; initially increased groundwater levels in the vicinity of the reservoir, and significantly reduced groundwater levels throughout most of the Szigetköz and beyond.

In an attempt to reduce the uncertainty surrounding the impact assessment, a programme of groundwater modelling was put in place by the Hungarian government, supported by an extensive set of field characterisation studies. Modelling results are now becoming available (Simonffy, 1994). A 3-dimensional groundwater flow model (MODFLOW), initially developed by the United States Geological Survey, has recently been extended to allow a more complete representation of river-aquifer interactions and is being used in the first phase of simulations. Further development at VITUKI has incorporated evaporation from riparian ecosystems and sub-irrigated agriculture. A regional model has been used,

including the Žitný Ostrov, to establish boundary conditions for more detailed modelling of the Szigetköz and adjacent areas. The model represents the aquifer by 11 vertical layers, with a variable horizontal mesh (minimum grid size 200x500 m). This results in approximately 50,000 model elements (*Figure 3.10*). The model includes a representation of the side-arm system.

As noted above, the effects of clogging are highly uncertain and were not considered in the modelling undertaken prior to 1989. *Plate 3.10 (Volume 5)* shows the model simulation of the pre-dam situation and a simulation of the average groundwater levels as a result of the Original Project, but with the optimistic assumption of a discharge of 200 m^3/s to the Danube channel. It is assumed that a moderate amount of clogging would take place in the reservoir and in the side-arm system (leakage factors 0.03-0.5 and 0.05-2.0 day^{-1}, respectively; this latter effect is conditioned on current experience of side-arm response).

Plate 3.11 (Volume 5) and *Table 3.4* illustrate the differences in average groundwater levels between these two cases. It can be seen that close to the dam, water level rises of in excess of 3 m occur, due to the impoundment. However, the loss of Danubian recharge results in significant changes throughout most of the Szigetköz. In a riparian strip alongside the Danube of an area 48.5 km^2, a 2-3 m decline in water level is predicted. An area of 128 km^2 has a decline of greater than 1 m; the total area affected by reduced *average* water levels is 282 km^2. In the lower Szigetköz, below the confluence of the Danube and tail-race canal, this decline is primarily due to the proposed dredging of the river bed.

Considering the case of a 50 m^3/s discharge in the Danube, a greater lowering of groundwater levels is predicted (*Table 3.4* and *Plate 3.11, Volume 5*, right-hand side map). A riparian area of 20 km^2 is now affected by a groundwater decline of 3 m or more; the total area affected by reduced levels is 310 km^2.
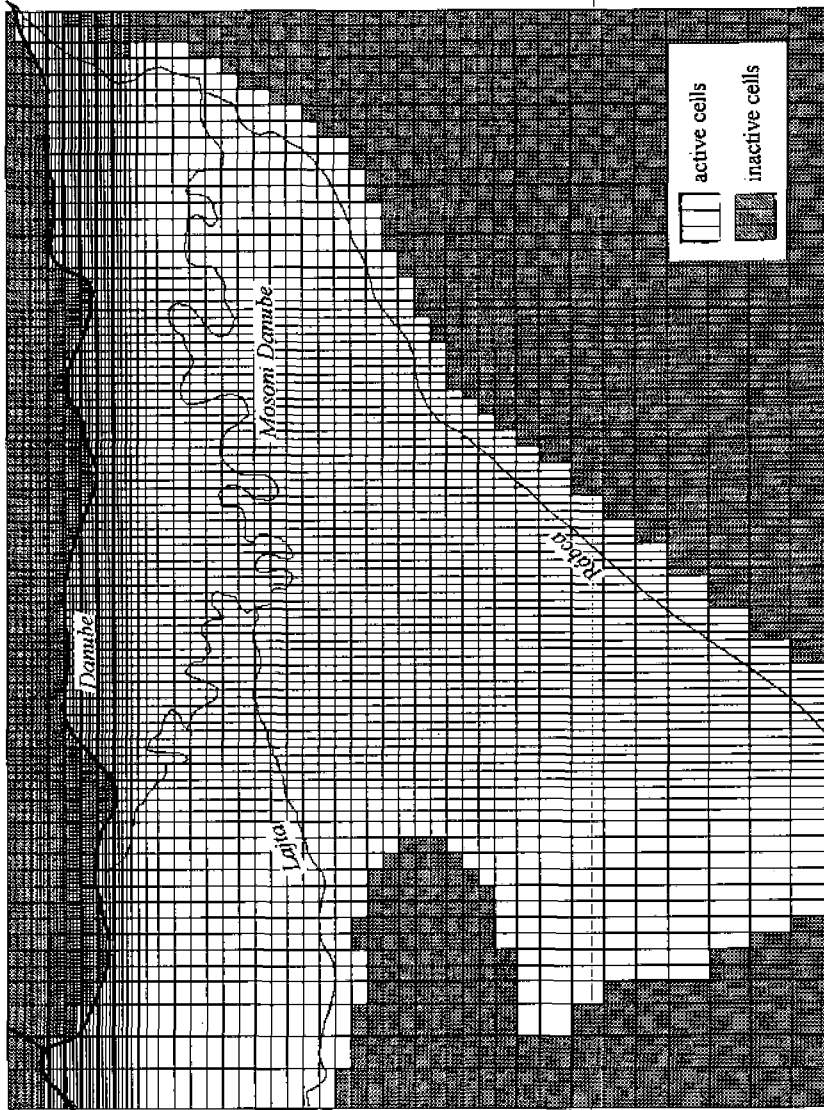
Figure 3.10: Mesh of the detailed groundwater model of the Kisalföld

Table 3.4: Areas where changes in the groundwater levels would have been observed, before and after the implementation of the Original Project

Changes in water level	Areas (km²)	
	discharge = 50 m³/s	discharge = 200 m³/s
decrease	310.8	281.5
> 3 m	20.4	--
2 m - 3 m	55	48.5
1 m - 2 m	89.4	79.2
0 m - 1 m	146.0	153.8
increase	76.5	95.5
0 m - 1 m	44	63
1 m - 3 m	18.4	18.4
> 3 m	14.1	14.1

The uncertainty in the effects of clogging is also illustrated in *Plate 3.16 (Volume 5)* for the 200 m³/s flow conditions. Assuming a more pessimistic but not unrealistic scenario for sediment deposition and clogging, gives further reductions in groundwater level of up to 2 m, including some areas where a 1-2 m decline is already predicted.

Apart from a reduction in levels, changes in the magnitude of direction of groundwater flows occur. The annotation on *Plate 3.10 (Volume 5)* indicates a reversal of flows in the vicinity of the main Danube channel. Recharge from the channel is replaced by drainage towards it. The changing role of the main Danube and side-arms in providing recharge sources is shown schematically in *Figure 3.11*.

The effect on the supply of groundwater to vegetation by capillary rise is illustrated for average groundwater levels in *Plate 3.12 (Volume 5)*. It can be seen in *Figure 3.12* and, for the cross-sections in the Upper and Middle Szigetköz in *Plate 3.13 (Volume 5)*, that in the pre-dam state, average groundwater levels only just intersect the fine covering layer in the upper cross-section. After dam construction, the water levels are lower, and recharge from the side-arm system occurs. In the second cross-section, average water-table conditions lie within the fine layer pre-dam, but would fall below after implementation of the Original Project.

The supply of groundwater as sub-irrigation by capillary rise depends on the position of the water-table in relation to the depth of fine soil, and the groundwater levels vary according to the seasonal pattern of flows, high levels usually

coinciding with the period of maximum vegetation need. Hence three classes of area can be identified, namely:

a) those areas for which the water-table is permanently above the fine soil interface;
b) areas for which it is above the interface under average groundwater conditions, and
c) areas for which it temporarily reaches the fine soil, under conditions of high Danube water levels.

Average groundwater levels underestimate the full impact of the Original Project. The natural annual variability of groundwater levels has been represented in *Plate 3.7 (Volume 5)*, which demonstrates that over most of the Szigetköz, groundwater levels in the spring/early summer are up to 1 m higher than the average values. After construction of the Original Project, according to the Joint Contractual Plan, this seasonal variation would be lost. Hence the seasonal maximum post-dam would be represented by the average condition. The implications of this are illustrated in *Plate 3.12 (Volume 5)* and *Table 3.5*. Before dam construction, seasonally varying water-tables would reach the fine soil layer over approximately 350 km^2. It will be seen that the discussion of steady-state conditions after dam construction would reduce this to approximately 186 km^2, i.e. a 50% reduction (55% in the Szigetköz alone).

Table 3.5: The relative position of the groundwater and the covering layer before and after the implementation of Original Project

Relative position	Area (km^2)		
	Before Original Project	After Original Project	Differences
continuously sub-irrigated	135	116	19
sub-irrigation under average groundwater conditions	125	57	68
temporarily sub-irrigated during high Danube water levels	93	13	80

The impacts on soils, ecology, agriculture and forestry are discussed in the following chapters. It should be noted, however, that in the vicinity of Sap, where flows return to the main Danube channel, a diurnal cycle of water level variation would be imposed by peak power generation. The effect on soils is discussed in *Chapter 5*.

There are also important concerns relating to water quality. They are discussed and quantified in *Chapter 3.5*, below. They relate principally to the problem of sediment degradation in the reservoir, leading to a loss of aerobic conditions and mobilisation of metals in the groundwater, and also to the impact of changing

regional groundwater flows. The loss of Danube recharge would lead to the ingress of poorer quality waters from adjacent areas and also a change in flow paths from existing known and unknown point sources of pollution. Where groundwater levels increased, new sources of pollution might alter the groundwater system.

During the discussions following the initial agreement of the Original Project, solutions were proposed to reduce adverse effects by some increase of Danube flows, the construction of weirs in the main Danube channel, and supplementary recharge systems.

The evaluation of these systems is highly complex, and even with a current state of the art capability for integrating flow, sediment deposition/erosion, sediment clogging and chemical degradation, groundwater flow and groundwater quality models, a high level of prediction uncertainty is inevitable. It was certainly the case that the effects of these proposals could not be adequately estimated in 1989, and despite strenuous technical efforts by both sides, that remains the situation at present. Principal concerns for groundwater relate to the effects of sedimentation on clogging and chemical degradation, and the impact of reduced levels of temporal variability.

ORIGINAL SITUATION

Danube

side arm

recharge only
during and after floods

reductive
conditions

sediments
with organic matter

localized
boundary

lenses with
organic matter

oxidative
conditions

oxidative
conditions

recharge from
the Danube

AFTER VARIANT-A

Danube

side arm

sediments
with organic matter

recharge only
during floods

reductive
conditions

lenses
with organic matter

mixing of
oxidative and reductive
waters

extending boundary

oxidative
conditions

recharge from
artificial recharge
system

oxidative
conditions

Figure 3.11: Schematic diagram of Szigetköz recharge sources
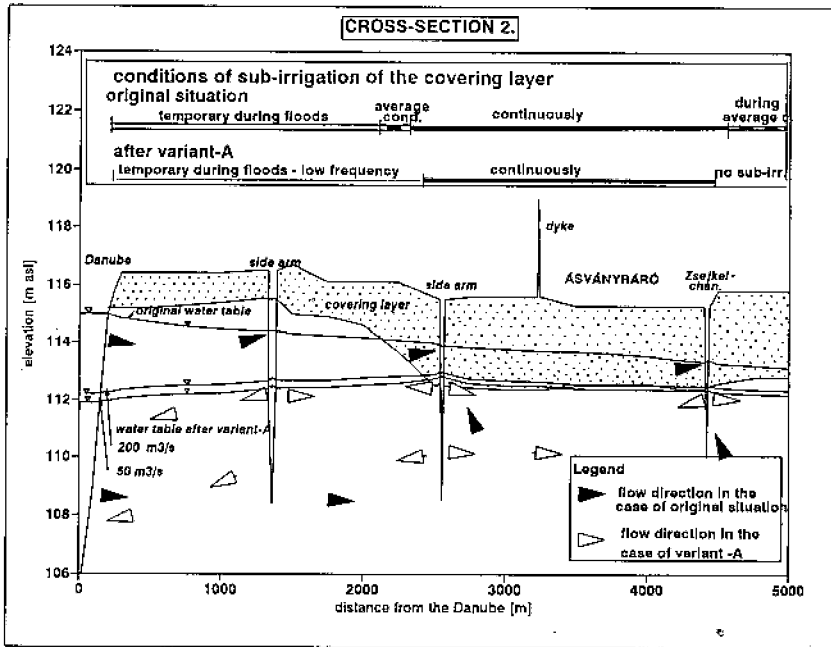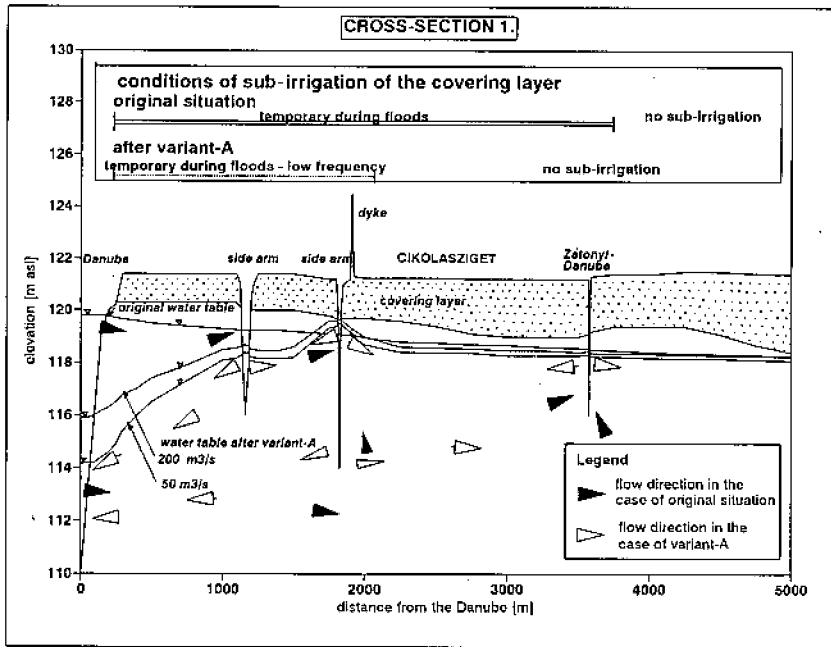
Figure 3.12: Groundwater levels before and after Original Project. a) cross-section 1; b) cross-section 2 (cf. Plate 3.13, Volume 5).

3.4.2.2 Gönyü to Nagymaros

The reach from Gönyü to Nagymaros would have been affected by the backwater of the Nagymaros Reservoir. A major concern here is the effect of sediment deposition on the yield and quality of bank-filtered wells. This is discussed in detail in *Chapter 3.6* below.

An additional problem concerns the impact of elevated surface water levels on groundwater. Solutions were proposed to remedy the patterns of water-table rise in adjacent low-lying areas, principally the Esztergom and Komárom lowlands. This involved the continuous pumping of groundwater from an extensive set of relief wells and interception canals (Ujfaludi, 1994). It was noted that particular problems were likely to arise in the islands of this reach and that strategic sites, e.g., the Primás palace (an important historical monument) were at risk. While such solutions are technically feasible, if expensive in terms of capital and, in particular, running costs, there are also associated risks. These obviously include pump failure, but poor quality of installation and/or maintenance can cause local damage.

The relationship between the karst water of the Transdanubian Mountains and the Danube was introduced above. In the late 1980s, there was extensive discussion of the potential impact of the Nagymaros Dam on the inter-connections, and a divergence of opinion between hydrogeologists concerning the impact (Erdélyi, 1984, 1989 and Lorberer 1989a, 1989b). Current understanding is reviewed by Lorberer (1994), based on a detailed field investigation programme undertaken from 1987 to 1989, and subsequent numerical analysis.

At Esztergom, the reduction in karst water levels induced inflow of Danube water from 1984 onward, and it is believed that this may have led to an observed drop in temperature and concentration of solutes in the water supply from a former spring to an open-air swimming pool. Additional ingress to the aquifer is likely due to the Nagymaros backwater effects with potential adverse effects on hot springs and wells. Given the localised nature of flow in karst systems, this is difficult to prevent, although grouting and other rock sealing measures have been proposed as a possible solution. Modelling of karst systems is highly uncertain, given the potential importance of (unknown) preferential flow-paths, but simulations indicated pressure increases of 3.3 m due to the dam and increased infiltration from the Danube of 1.5-2.0 m³/min (*Figure 3.13*).

It was suggested that at Dunaalmás the main effect on the karst system would be indirect, leading to increased infiltration of 1.2-1.5 m³/min, although two former springs could provide direct communication.

It was also noted that proposed pumping measures to control water levels in the Kis-Duna would increase the transport of background pollution at Esztergom.
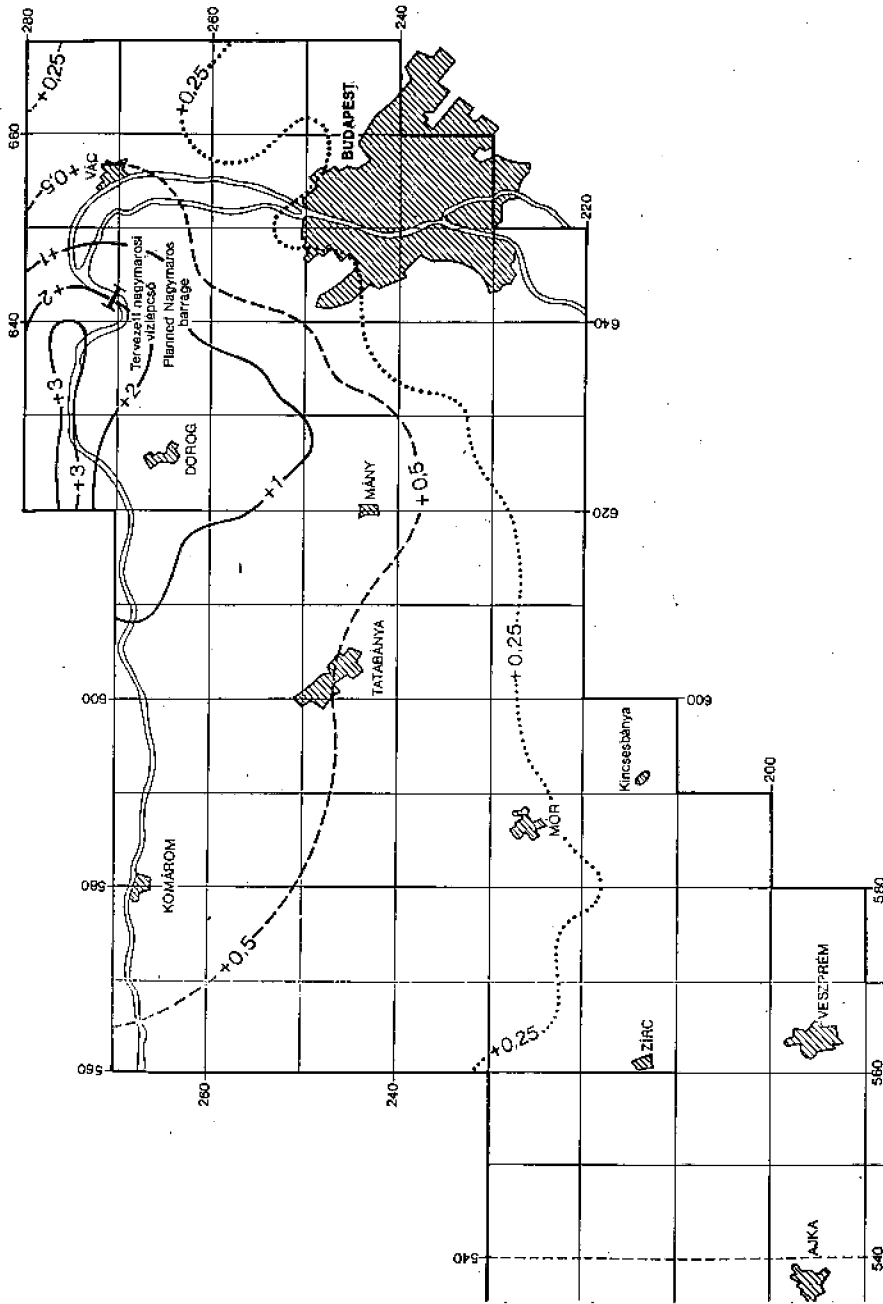
Figure 3.13a: Additional head increase (m) due to the operation of the Nagymaros barrage from 1992, calculated using the regional model, scale 1:2000 (after Lorberer, 1994)
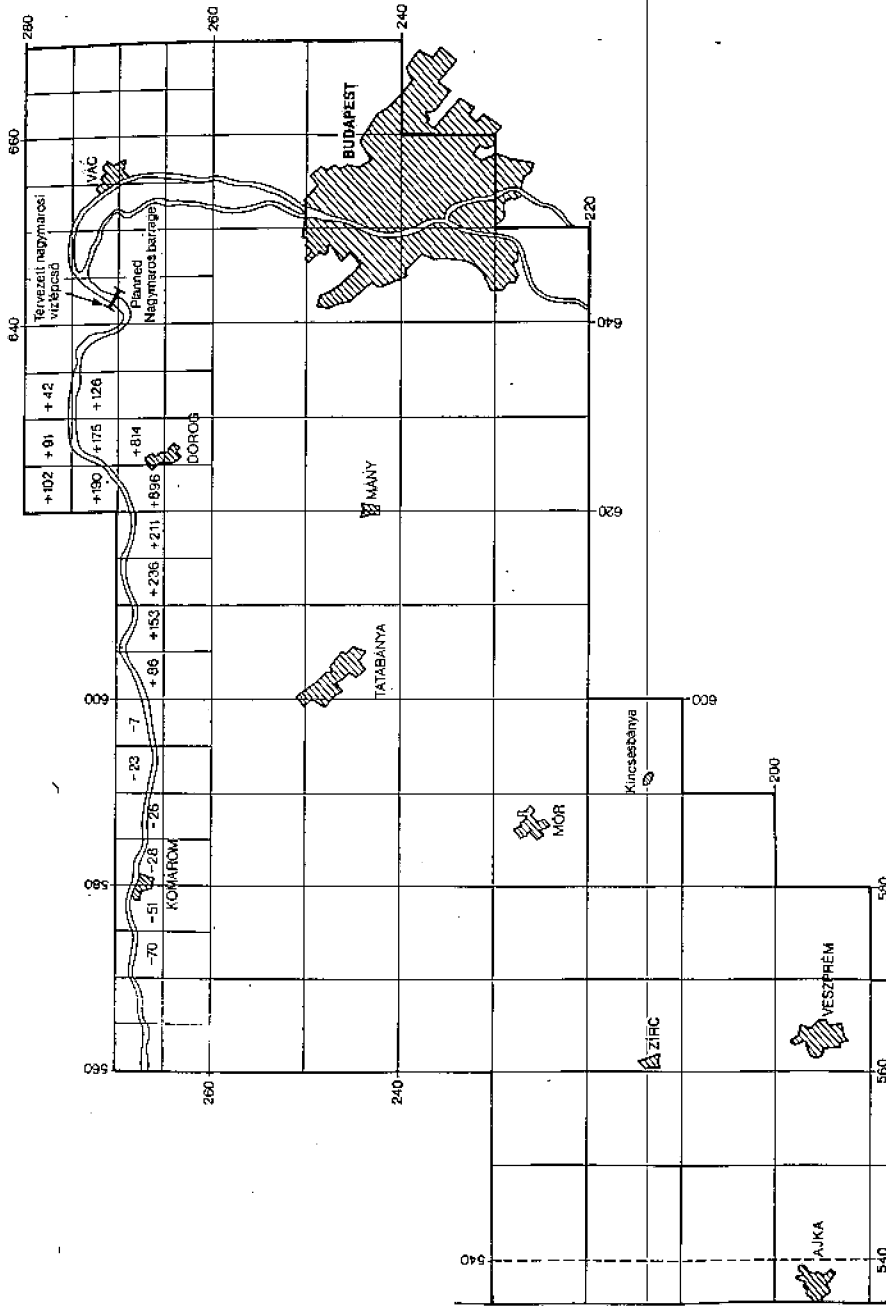
Figure 3.13b: Additional trans-percolations (m³/d) due to the operation of the Nagymaros barrage from 1992, calculated using the regional model, scale 1:2000 (after Lorberer, 1994)

3.4.2.3 Nagymaros-Budapest

The primary impacts anticipated in this reach are associated with the yield and quality of Budapest water supply, and are discussed in *Chapter 3.6*, below. Impacts on thermal waters are expected to be limited.

3.4.3 IMPACTS OF VARIANT C

Impacts of Variant C on groundwater have been, on the Hungarian side, mainly related to changes in groundwater levels, fluxes, and flow-directions in the Szigetköz.

As noted above, under pre-dam conditions, groundwater levels reflect Danube water levels. Following construction of Variant C, average Danube water levels have fallen by 4 m at Rajka, 3 m at Dunaremete (*Figure 3.8*). The observed groundwater changes under average flow conditions are shown in *Plate 3.13 (Volume 5)*. Maximum reductions in excess of 3 m occur in the close proximity of the main Danube in the upper Szigetköz. A riparian strip 1.5 km wide experiences reductions in excess of 2 m along most of the affected main Danube channel. A total of 297 km^2 suffers water level reductions (*Table 3.6*). Groundwater level increases of up to 0.25 m occur over an area of 24 km^2.

Table 3.6: Areas where changes in the groundwater have been observed, before and after the implementation of the Variant C

Changes in water level	Areas (km^2)	
	average Danube flows	high Danube flows
decrease	297	346
> 3 m	3	22
2 m - 3 m	24	47
1 m - 2 m	51	35
0 m - 1 m	219	242
increase		
0 m - 0.25 m	24	0

Considering typical high flow conditions in the Danube, as expected, impacts are greater (*Plate 3.13, Volume 5*). The total area affected by reductions in groundwater levels is not much larger (346 km^2), but the extent of major reductions is significantly increased. Reductions of 3 m or more apply to a 22 km^2

strip, 1-2 km wide and some 25 km long. Reductions of 2 m or more apply to an area of 69 km^2, extending nearly 5 km from the Danube (*Table 3.6*). The results confirm the nature of changes presented in the Original Project simulations. The average groundwater levels are shown in *Plate 3.14 (Volume 5)*. The main Danube channel, formerly a major recharge area, is now acting as a drain. The primary recharge to the aquifer is from the reservoir, and the side-arm system.

The impacts on capillary rise are presented in *Table 3.7* for the growing season April-August. A total area of 127 km^2 suffers reduction in water availability, and 37 km^2 now have a total loss of sub-irrigation supply.

The time-series of groundwater fluctuations across the two sections indicated in *Plate 3.13 (Volume 5)* confirm the dramatic change in both groundwater levels and variability following implementation of Variant C.

Table 3.7: The relative position of the groundwater and the covering layer before (1990) and after (1993) the implementation of Variant C

Relative position	Area (km^2)		
	Before Variant C April-August 1990	After Variant C April-August 1993	Differences
continuously sub-irrigated	112	78	34
sub-irrigation under average groundwater conditions	81	25	56
temporarily sub-irrigated during high Danube water levels	90	53	37

3.5 GROUNDWATER QUALITY

by Howard Wheater

3.5.1 THE NATURAL SYSTEM

The groundwater flow regime in the Szigetköz and adjacent areas has been discussed above. In the pre-dam situation, groundwater in the Szigetköz was recharged primarily from the gravel bed of the main Danube channel. The quality of this recharged water was excellent, as shown by analysis of the quality of bank-filtered groundwater along the length of the main channel between Rajka and Ásványráró, rkm 1849-1815 (Horváth and Tóth, 1994). In particular, the water was aerobic; the dissolved oxygen content was sufficient to oxidise the low amounts of

degradable organic material, and hence reduced redox species such as iron, manganese and ammonium were only present in low concentrations (*Table 3.8*).

Table 3.8: Mean concentrations of reduced redox species in bank-filtered water in 1991. Samples taken along the main channel of the Danube between Rajka and Ásványráró, 1849-1815 rkm (Horváth and Tóth, 1994).

Mean concentration (mg/l)		
Fe^{2+}	Mn^{2+}	NH_4^+
0.05	0.02	0.05

The influence of Danube water on the groundwater of the Kisalföld is illustrated in *Figure 3.7*, which is based on stable isotope analysis. Oxygen-18 data indicate the spatial distribution of Danube water, and hence its influence on groundwater quality. Tritium, which peaked in surface waters some thirty years ago as a result of atmospheric nuclear tests, has now penetrated to the middle of the Szigetköz. This 30-year old front provides an important illustration of the time-scale of contaminant transport in groundwater; travel times indicated are in the range 250-400 m/yr (Liebe, 1994).

As the influence of Danube water decreases, adverse changes in groundwater quality are observed. To the south-west of the Szigetköz there is an increase in dissolved solids, including a substantial increase in iron, manganese and ammonium. In the lower Szigetköz, in the vicinity of Gyôr there is also an increase in the reduced redox species, in samples from deeper wells a mixing with Pliocene water has been observed, too. However, for the Szigetköz in general, groundwater quality is good. Where pollutants have been observed, they have been limited to the top 20 m of the aquifer and result from isolated cases of point source pollution, usually nitrates from agricultural or domestic wastes. In the deeper groundwater used for public supply, highest nitrate values (10 mg/l) occur between the Mosoni Danube and the river Lajta to the south-west, but are well below the drinking water standard (Liebe, 1994).

The influence of organic-rich sediment on groundwater recharge is discussed in detail in *Chapter 3.5.2.1*. Degradation of organic material can consume the available oxygen, leading to chemical reduction, and the mobilisation of iron, manganese and ammonium. Examples are presented from international experience of dams and associated floodplains, and, in *Chapter 3.6*, from bank filtered wells in Hungary.

The side-arm systems of the Szigetköz are rich in organic sediment, and, as discussed below, are observed to give rise to reducing conditions. However, in the pre-dam situation their impact on groundwater recharge was minimal. As will be discussed below, this is no longer the case.

3.5.2 IMPACTS OF THE ORIGINAL PROJECT

3.5.2.1 International experience of groundwater quality degradation

Several published studies provide convincing evidence of groundwater quality degradation associated with river impoundment, e.g. Hahn *et al.* (1979), Märki (1971). More recent Austrian examples are particularly relevant. Frischherz *et al.* (1986) report the effects of the Danube Power Station Abwinden-Asten on an adjacent well field of capacity 48,000 m^3/d. They note the following primary changes:

– increase in water level of the reservoir

– decrease in flow velocity in the backwater reaches

– decrease in water level fluctuations

which lead to:

– increased sedimentation

– oxygen depletion during infiltration of water through the sediment into the groundwater

– resolubilisation processes from the sediment due to the anaerobic conditions

In this case, the deposited sediment had a high organic load, but the time-scales and consequences are important. The reservoir was constructed between 1976 and 1979. In 1979 manganese was observed for the first time in one well, followed by the appearance of ammonium (mid-1980) and dissolved iron (1981). In a second well, ammonium appeared for the first time towards the end of 1980, followed by manganese in mid-1982 and iron in mid-1983. The consequence was the occurrence of bacterial slimes in the water supply system, giving rise to "significant technical problems."

Possibly the most intensely-studied Danube reservoir has been the Altenwörth, also in Austria (Hary and Nachtnebel, 1989). Investigations of groundwater quality in the vicinity of the Altenwörth barrage, in comparison with non-impounded river reaches, showed the following impacts of the barrage system:

– increased sedimentation in the reservoir due to lower flow velocities;

– infiltration from the reservoir to groundwater occurring through sediment with a high organic content;

– a decrease of groundwater fluctuations, with subsequent reduction of oxygen supply to the soil;

– the possibility of permanent waterlogging of soil horizons with a high organic load;

– the prevention of large-scale inundations, and hence the reduction of supply to soils and groundwater of oxygen-rich surface waters.

These changes in the surface and groundwater flow regimes led to the formation of areas of reduced or zero oxygen content, the subsequent mobilisation of iron, manganese, and ammonium, and some increase in organic load and heavy metals. For example, it is noted that "In the northern floodplain, for which extensive data is available, the groundwater quality indicates an oxygen-depleted or oxygen-free zone. Simultaneously, increased iron and manganese concentrations were found after a period of delay of a few years after the power station construction."

3.5.2.2 Impacts of the Dunakiliti-Hrušov Reservoir

The impoundment of the Danube at Dunakiliti would have led to substantial changes in the groundwater flow regime. This in itself can lead to problems of groundwater quality, since changing groundwater flow paths can modify the direction and time of travel of existing pollutants. However, the changing pattern of groundwater recharge may also be associated with complex and extensive problems of water quality degradation. These are explained below, but are also fully recognised and discussed in the annexed paper by Mucha (1990) and in Mucha and Paulikova (1991).

In the Dunakiliti Reservoir, settling of suspended sediment and clogging of the reservoir bed were expected. Hence filtration through the accumulated silt could be expected to be associated with anaerobic conditions due to organic degradation, as discussed elsewhere.

It should be recognised, as is evident from the international experience, that these processes may not appear for some years. It must also be acknowledged that a highly complex set of process interactions is involved, including sediment spatial deposition patterns, the physical effects of consolidation and clogging, and chemical degradation, which can only be predicted, given the current state of the art, with a high level of uncertainty.

Water quality changes in the infiltrating water from the reservoir have been estimated (László, 1994b), based on a calculation of redox conditions, considering the sequential oxidation of biodegradable organic material, and the subsequent application of the geochemical equilibrium model, MINTEQ (Batelle Pacific North West Laboratory).

A sensitivity analysis was undertaken, considering the ranges of uncertainty in the key parameters (*Table 3.9*). These calculations were carried out for the following parameter sets:

1. The parameter values most favourable for aerobic conditions;

2. The parameter values least favourable for aerobic conditions;

3. A mean parameter set.

The results indicated reducing conditions in cases 2 and 3. Given the uncertainties, it is considered that the mean parameter values provide the most reliable prediction.

The MINTEQ model considers metal speciation under chemical equilibrium based on thermodynamic relationships. It was similarly applied in a sensitivity analysis, considering a realistic range of parameter values (*Table 3.10*). It must be recognised that a high degree of uncertainty is involved, in particular due to limited information about the solid iron and manganese species. Nevertheless, the mean parameter values result in maximum concentrations of 25 mg/l iron and 5 mg/l manganese in anoxic groundwater, compared with Hungarian and WHO (1993) drinking water standards of 0.2-0.3 mg/l for iron and 0.1 mg/l for manganese (*Table 3.11*).

The impact on the groundwater system will depend on the distribution of sediment within the reservoir. On the assumption that aerobic conditions can be maintained under the former river channel within the reservoir, *Plate 3.15 (Volume 5)* indicates the water quality implications.

In the Original Project, groundwater recharge would have occurred from the reservoir and from other recharge sites, associated with the supplementary floodplain recharge system. Anaerobic groundwater is also expected from these sites (*Plate 3.15, Volume 5*), and from the subsequently proposed remedial measures, field evidence is discussed below, in the context of Variant C.

Table 3.9: Parameter Ranges for Redox Calculations

* Dissolved oxygen level in the reservoir water	5-10 g/m³
* Nitrate level in the reservoir water	5-10 g/m³
* BOD of the reservoir water	2-6 g/m³
* Amount of settling fines	0.01-0.05 m/year
* Biodegradable fraction of settling fines	0.5-1 %
* Seepage velocity	0.02-0.1 m/d

(Underlined numbers are the most favourable for aerobic conditions)

Table 3.10: Parameter Ranges for Chemical Speciation Modelling

water temperature	5-15 °C
redox potential	0-50 mV
pH	6.5-7.5
hydrogen-carbonate	150-250 mg/l
sulphate	25-35 mg/l
chloride	15-25 mg/l
calcium	30-70 mg/l
magnesium	10-30 mg/l
sodium	5-10 mg/l
potassium	2-6 mg/l

Iron and manganese precipitations initially present in the solid matrix and subject to equilibrium dissolution

Table 3.11: Comparison of International Drinking Water Standards for Selected Parameters

		EC (1980)		Hungarian (1989)		WHO (1993)
		Guide level	MAC	Guide level	MAC	MAC
Nitrates	NO_3 mg l^{-1}	25	50	20	40	50
Ammonium	NH_4 mg l^{-1}	0.05	0.5	0.1	0.5	1.5
Iron	Fe µg l^{-1}	50	200	200	300	300
Manganese	Mn µg l^{-1}	20	50	100	100	100
Arsenic	As µg l^{-1}	-	50	-	50	10

MAC=Maximum Admissible Concentration
EC (1980): European Community Drinking Water Directive (80/778/EEC)
Hungary (1989): Hungarian Drinking Water Standards (HSS, 1989)
WHO (1993): World Health Organisation Guidelines for Drinking Water Quality

3.5.2.3 Impacts of Variant C

Hungary does not have access to groundwater quality or sediment data from the existing reservoir. However, potential threats to the quality of the Bratislava water supply from the Samorin waterworks as a result of the project were identified by the CEC (1992). It is known that substantial efforts were made by Slovakia to minimise sediment deposition in that part of the reservoir adjacent to existing water supply wells (see Refsgaard *et al.*, 1994); and that it was considered necessary to re-site wells to prevent degradation of the quality of the water supply (CEC, 1992/1993 reports). This is evident confirmation of the risks discussed above.

Hungarian observations have focused on the quality of groundwater recharged from the side-arm system of the Szigetköz. A set of 62 observation wells in 11 groups were established along the banks of side-dams and canals (*Table 3.12* and *Plate 3.15, Volume 5*), sampling the upper 14.5 m. Data include in situ temperature and conductivity, and laboratory analysis of major ions, metals, organics, and nitrogen redox species. Results from August and September 1994 are illustrated in *Figures 3.14* to *3.19*. It can be seen that in general reductive conditions predominate. Although the data display considerable variability, for 9 of the 11 well groups, mean levels of iron exceed EC Maximum Allowable Concentrations for drinking water, and mean levels of manganese exceed EC guide levels. For all sites, maximum levels of ammonium exceed EC guide levels. Nitrate levels suggest that well groups 1 and 2 on the side-arm recharge system maintain aerobic conditions (although unacceptable levels of iron occur at 1), and these sites have, as yet, little sediment deposition, in contrast to locations 3-6 on the side-arm system where clearly reducing conditions apply.

Toxic elements are generally present below limit values for drinking water, but a notable exception is arsenic, for which mean values exceeded WHO limits at some of the well groups. Again, this occurrence is associated with the release of naturally occurring arsenic under reducing conditions.

Well group 11, very close to the main Danube channel is of particular interest. It was noted (*Table 3.12*, below) that recharge from the Danube was of high quality water. In 1994, the water quality at this site has clearly shown reducing conditions and unacceptable groundwater quality, following the change in recharge pattern.

It can be concluded that:

Before the damming of the Danube, good quality bank-filtered water recharged the alluvial aquifer from the gravel bed of the Danube.

After the damming, the recharge pattern has dramatically changed. Although subject to uncertainty, calculations indicate that recharge from the reservoir is

likely to be of poor quality. Concern over this issue is evident from Slovak activities. It has been demonstrated from Hungarian data that poor water quality has occurred adjacent to the side-arm system. The clear implication is that recharge will result in long-term adverse changes to the quality of this major alluvial aquifer. Recharge quality in general exceeds drinking water standards for iron and manganese and ammonium. In some cases the toxic element arsenic is also present in unacceptable concentrations. Similar effects are also expected as a result of the remedial measures.

Table 3.12: Characteristic parameters of the observed well groups

Identification number of well group	Number of the wells observed for the water quality	Range of horizontal distances of the observed wells from the surface water (m)	Range of depth of well filters of the observed wells (m)
1	6	2-17	1.2-14.5
2	5	2-23	1.2-7.8
3	8	5-19	2.5-14.5
4	5	10-61	3.2-15
5	8	3-30	1.8-4.5
6	5	4-14	1-8.2
7	5	6.5-12	3-11
8	5	5-24	1.5-4
9	6	7-45	3-14.5
10	7	4-29	2.8-11
11	2	17	7.0-10.7
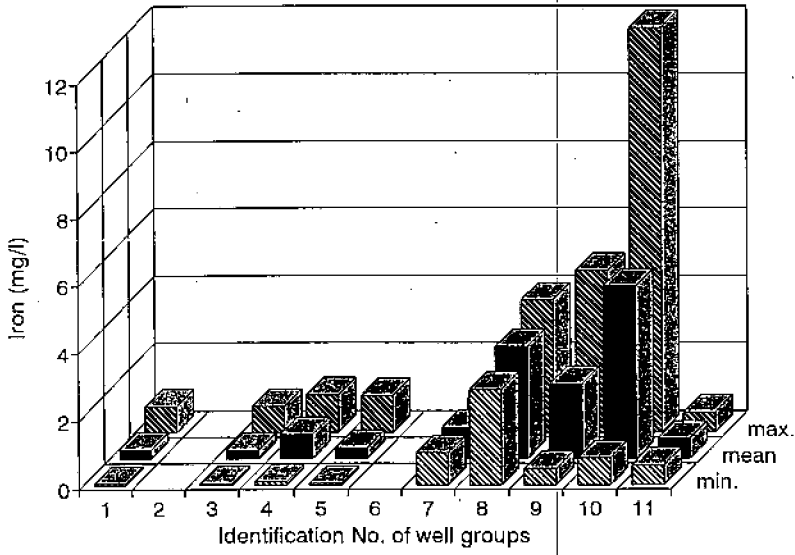
Figure 3.14: *Characteristic iron concentrations in the observation well groups (after László, 1994a)*
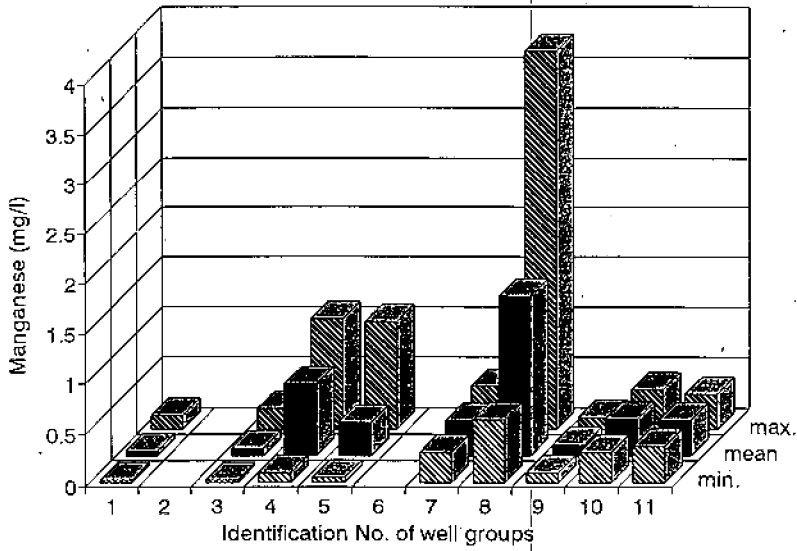
Figure 3.15: *Characteristic manganese concentrations in the observation well groups (after László, 1994a)*
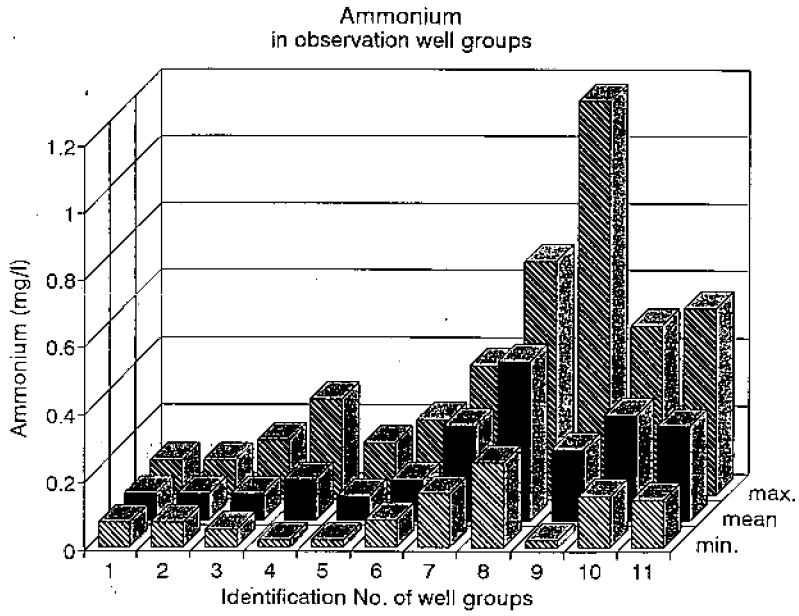
Figure 3.16: *Characteristic ammonium concentrations in the observation well groups (after László, 1994a)*
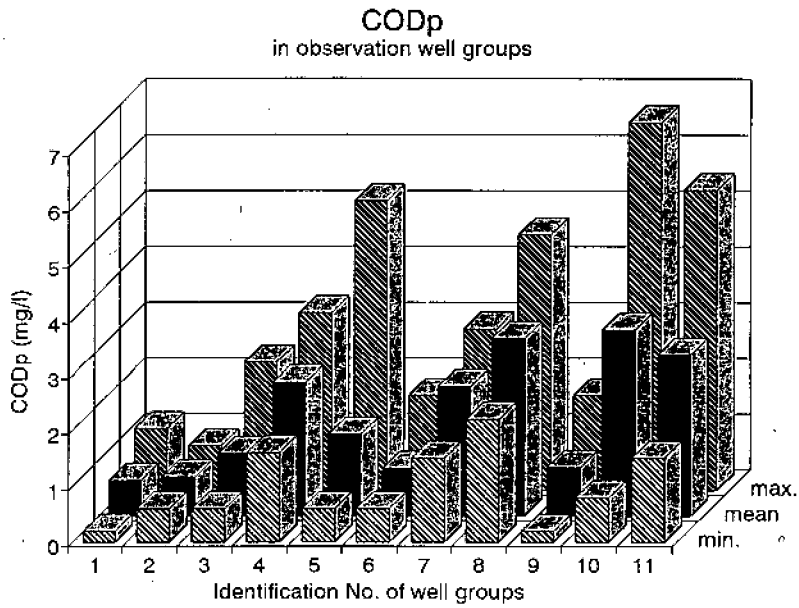
Figure 3.17: *Characteristic COD concentrations in the observation well groups (after László, 1994b)*
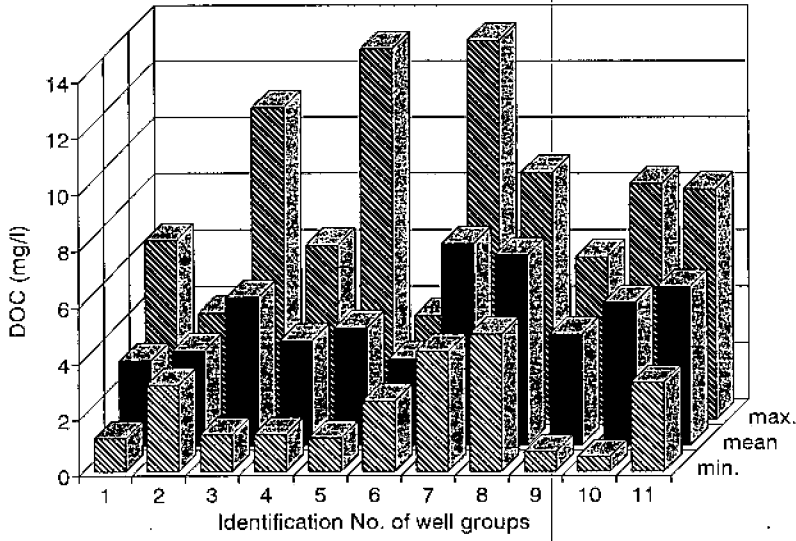
Figure 3.18: Characteristic dissolved oxygen concentrations in the observation well groups (after László, 1994b)
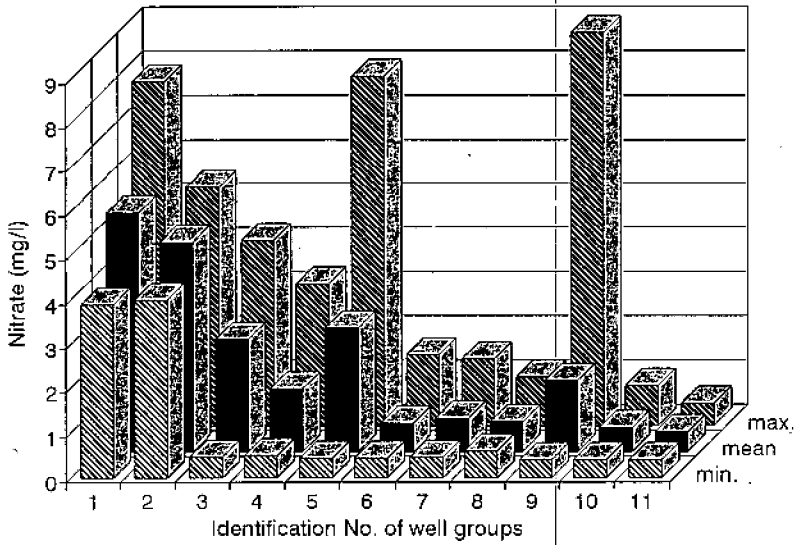
Figure 3.19: Characteristic Nitrate concentrations in the observation well groups (after László, 1994b)

3.6 BANK-FILTERED WATER SUPPLIES

by Howard Wheater

3.6.1 EXISTING BANK-FILTERED WELLS

In the river reach from Gönyü to Budapest, bank-filtered wells have been developed to a varying extent to exploit the alluvial aquifer. Between Gönyü and Nagymaros, the reach influenced by backwater effects from the proposed dam at Nagymaros, major well-fields have an existing capacity of approximately 30,000 m^3/d (*Table 3.13* and *Plate 3.8, Volume 5*), and potential resources of 19,000 m^3/d and 75,000 m^3/d have been identified in the Ács-Komárom-Almásneszmély and Esztergom reaches (Hungarian Academy of Sciences, 1994).

Below Nagymaros, 64% of the Budapest Waterworks supply comes from the major well-fields to the North of the city, principally Szentendre Island (see *Plate 3.9, Volume 5*). It is therefore an issue of national importance to evaluate the potential risk to these resources, considering effects both upstream and downstream of the Nagymaros dam.

Table 3.13: Existing bank-filtered well fields – Gönyü to Nagymaros

Waterworks	Capacity (m^3/day)
Komárom - Koppánymonostor	5,000-6,000
Nyergesújfalu	5,000-6,000
Tát	2,000-3,000
Esztergom - Prímás	12,000-13,000
Esztergom - Szentkirály	2,000
Szob	<1,000
Zebegény	<1,000
Dömös	<1,000

3.6.2 POTENTIAL RISKS TO BANK-FILTERED WATER SUPPLIES

Bank-filtration is used extensively on the major European rivers. It has been shown to be highly effective in removing contaminants, for example inorganic and organic pollutants, heavy metals, algae and bacteria (e.g. Sontheimer, 1980;

Hermann *et al.*, 1986 and Chorus *et al.*, 1992), although there is a dependence of removal efficiency on the length of the filter pathway. However, the water quality of bank-filtered wells is dependent on the chemical conditions in the filter layer. If chemically-reducing conditions develop, mobilisation of metals such as iron and manganese (and other heavy metal pollutants which may be present in river sediment) may occur, together with the generation of ammonium, and, in addition, serious clogging problems can arise due to bacterial activity (van der Kooij *et al.*, 1985).

The yield in terms of water quantity from bank-filtered wells is dependent on river water levels and the hydraulic connection with the river. This in turn is affected by the geometry and material properties of the riverbed.

The primary concerns for bank-filtered water supplies are associated with a combination of these two factors. Changes to river water levels and riverbed levels will affect yield; changing patterns of sedimentation will cause deposition of organic-rich sediment. Their long-term degradation can change the chemical state of the filter system, with serious adverse consequences.

In addition, it is not uncommon in international experience for adjacent groundwater to have inferior water quality to bank-filtered river water. Reduction in river bed hydraulic connection can lead to increased well capture of poorer quality water.

3.6.3 HUNGARIAN EXPERIENCE OF DEGRADATION OF BANK-FILTERED WATER QUALITY

The extent of dredging of the Danube has been discussed in *Chapter 2*. The Danube reach from Nagymaros to Budapest has been dredged for industrial purposes and also to some extent for navigation. River training works have also included the construction of groynes. Two examples illustrate the consequences of changing sedimentation patterns on groundwater quality.

3.6.3.1 The Surány Waterworks

This waterworks was constructed by Budapest Waterworks on Szentendre Island between 1968 and 1971. Following tests in 1965 and 1966 which showed potable quality water with no iron, manganese or ammonium, 20 wells were installed (*Figure 3.20*). Water quality problems emerged, and were initially analysed in the mid-1980s (László *et al.*, 1990). Data from 1984 show particularly high levels of manganese and ammonium in wells 7 to 9 (*Figure 3.21*). The time-series of manganese and ammonium concentrations from 1973 to 1984 is shown in *Figure 3.22* for wells Nos. 4 and 9. Concentrations in well No. 4 peaked in the mid-1970s, and declined thereafter, whereas a significant deterioration in well 9 continued.

The investigation programme extended to the riverbed, and included detailed sediment survey, additional investigation boreholes, and biological and chemical analysis. The field survey in the vicinity of well No. 7 revealed two sediment-filled troughs (*Figure 3.23*), extending also to wells 8 and 9. The processes of sediment degradation outlined above were indeed occurring, and the resulting concentration of manganese and ammonium can be compared with EC (1980) limits of maximum admissible concentrations of 50 μg/l (0.05 g/m^3) and 0.5 mg/l (0.5 g/m^3) respectively and guide levels of 20 μg/l (0.02 g/m^3) and 0.05 mg/l (0.05 g/m^3), respectively. It will be noted that ammonium levels in well 9 in 1984 reached 90 times guide levels, manganese 200 times guide levels.

Investigation of well 4 indicated that problems of sediment degradation had occurred, but that the sediment had been gradually scoured following a change in flow pattern associated with later groyne construction.

The question remained whether the effects observed in wells 7 to 9 were likely to be persistent, or short-lived. More recent data for wells 8 and 9 are presented in *Figures 3.24* to *3.29,* and show that unacceptable levels of manganese, ammonium and iron continue up to the present. The riverbed now appears stable in the vicinity of the wells. Hence the clear implication is that the original sediment deposition does indeed have long term effects.
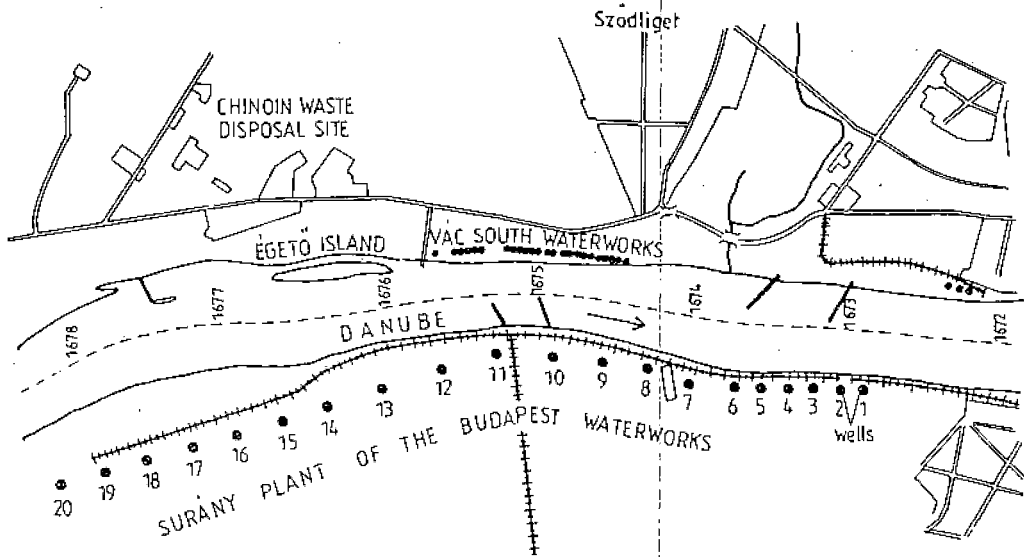
Figure 3.20: *Surány bank filtration well field along the Danube rkm 1673-1678*
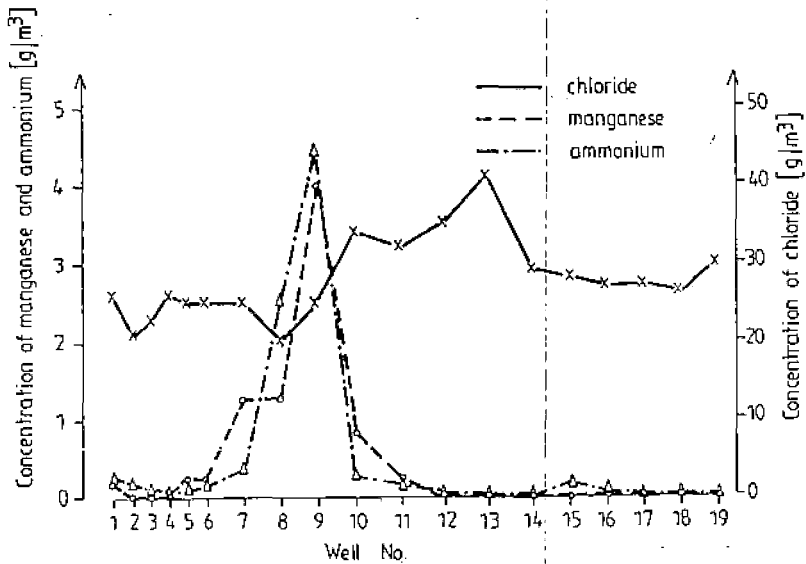
Figure 3.21: *Water quality in the Surány well field in 1984*
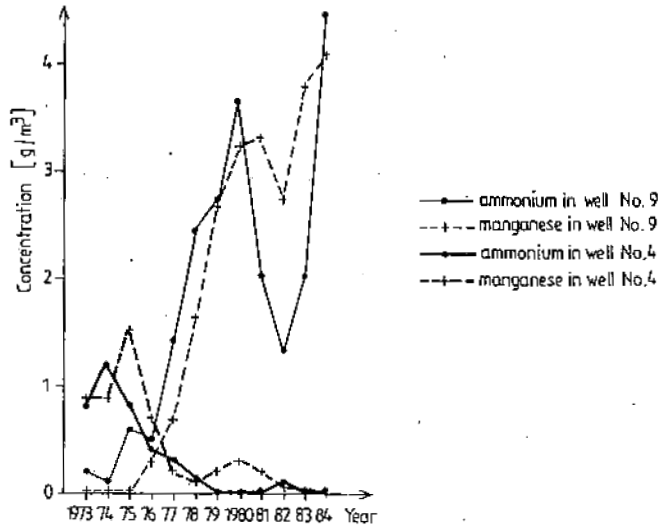
Figure 3.22: *Annual highest manganese and ammonium ion concentrations in the well No. 4 and No. 9 between 1973-1984*
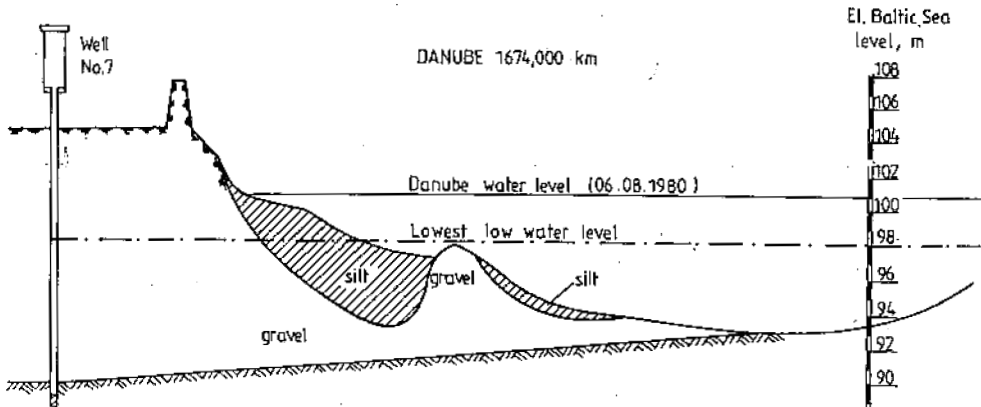
Figure 3.23: *Danube cross section through well No. 7*

Figure 3.24: *Annual maximum, minimum and mean ammonium concentrations in well No. 8 between 1988 and 1993*

Figure 3.25: *Annual maximum, minimum and mean ammonium concentrations in well No. 9 between 1988 and 1993*

Manganese in well No. 8
Budapest Water Works Surany well field
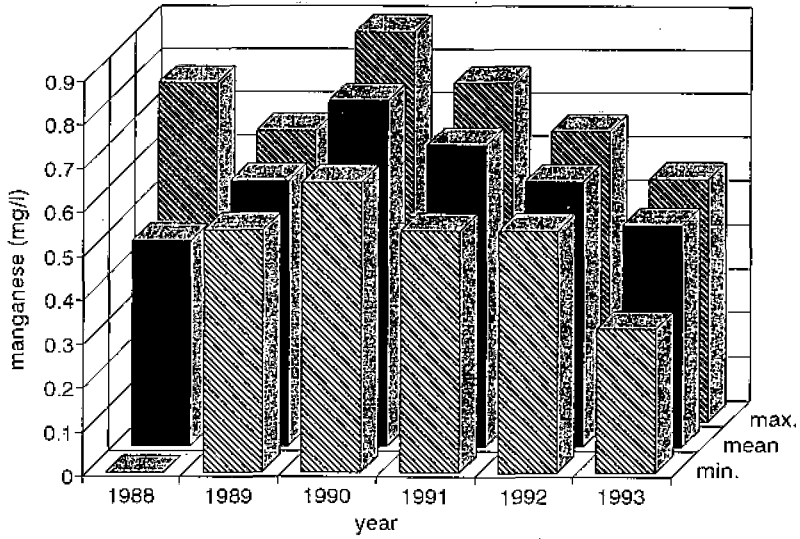
Figure 3.26: *Annual maximum, minimum and mean manganese concentrations in well No. 8 between 1988 and 1993*

Manganese in well No. 9
Budapest Water Works Surany well field
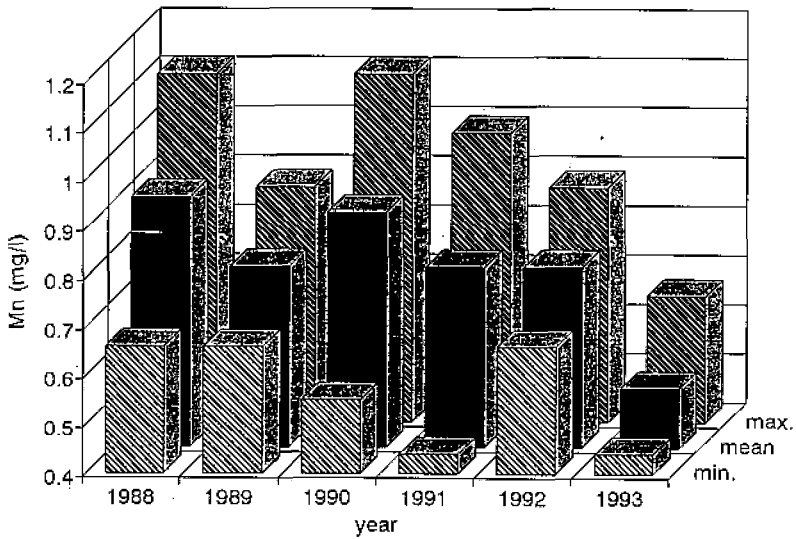
Figure 3.27: *Annual maximum, minimum and mean manganese concentrations in well No. 9 between 1988 and 1993*
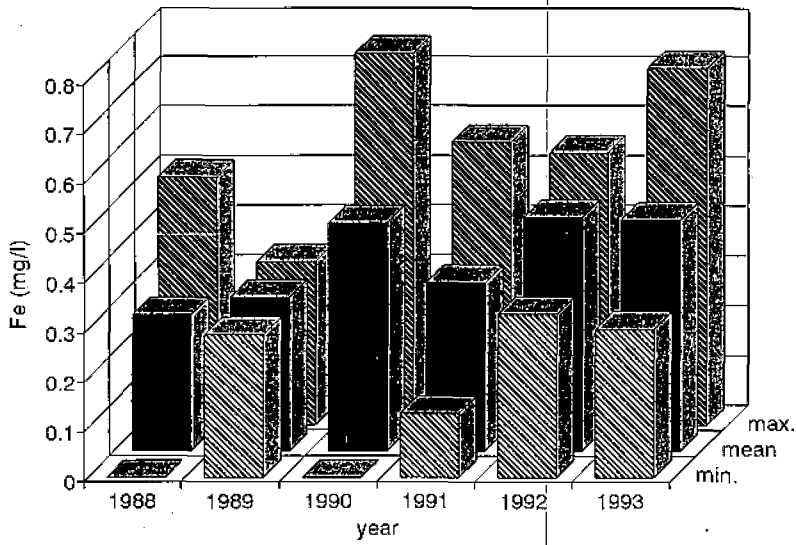
Figure 3.28: *Annual maximum, minimum and mean iron concentrations in well No. 8 between 1988 and 1993*
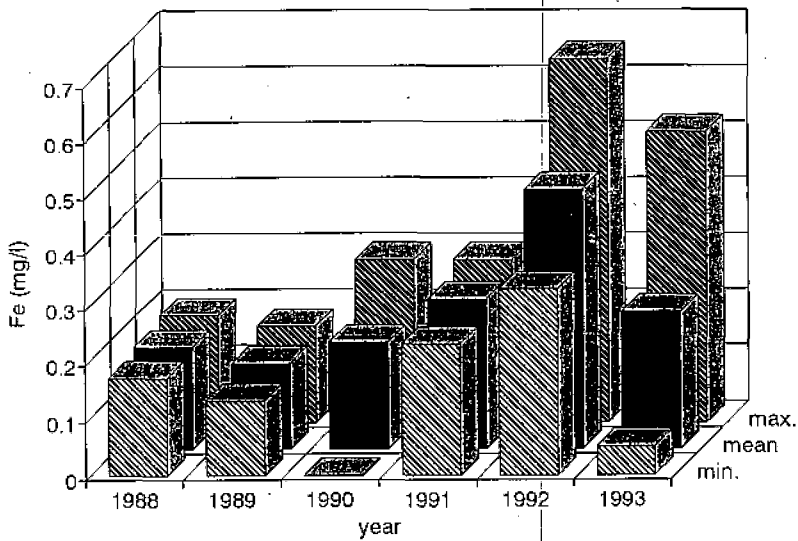
Figure 3.29: *Annual maximum, minimum and mean iron concentrations in well No. 9 between 1988 and 1993*

3.6.3.2 Nagymaros Waterworks

Two bank-filtration wells of the Nagymaros Waterworks of the Danube Regional Water Company were operated on the left bank of the Danube at rkm 1693 between 1963 and 1988. Rapid water quality deterioration began in both wells in the early 1980's, as shown in *Figures 3.30* and *3.31*. The manganese and ammonium concentrations exceeded drinking water limits and the operating licences for the wells were withdrawn. A Raney-type well was installed two kilometres downstream in 1986. Within six years the water quality became unacceptable. As can be seen from *Figure 3.32*, the results show a change of redox conditions leading to increased manganese and ammonium and reduced nitrate concentrations.

The adverse changes in water quality in these three wells occurred due to bed sediment deposition. It is believed to be a direct result of the Nagymaros coffer dam construction.
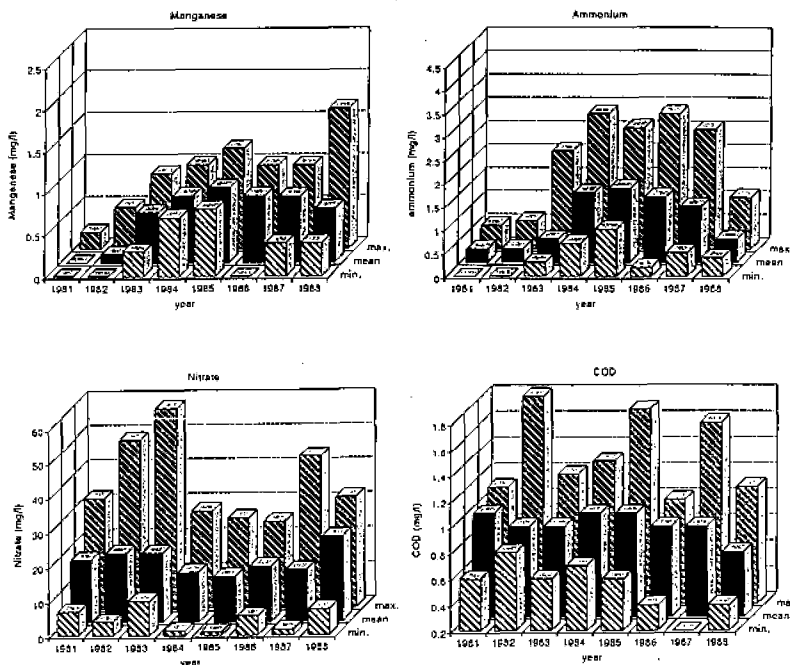
Figure 3.30: *Water quality of the bank filtration well No. 1, Nagymaros Waterworks*

114
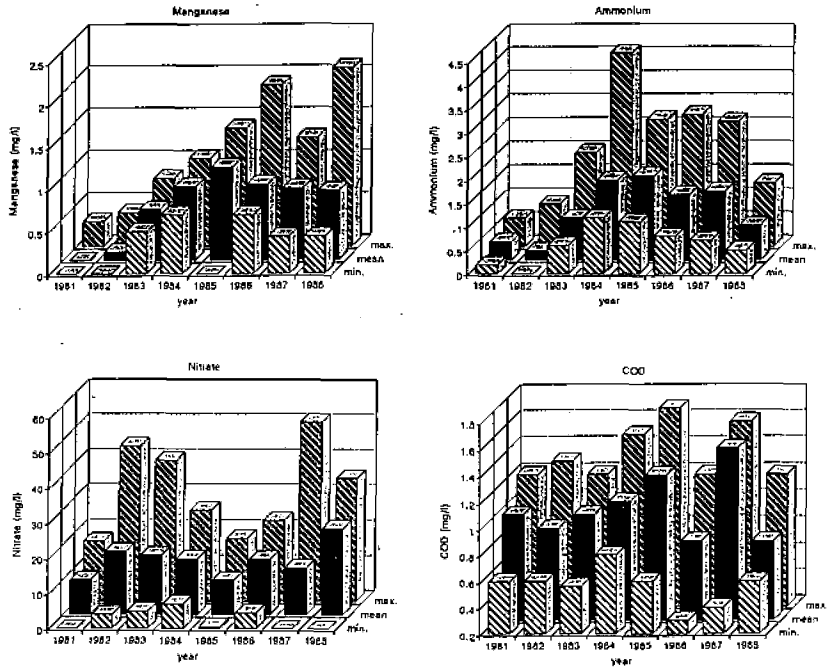
Figure 3.31: *Water quality of the bank filtration well No. II., Nagymaros Waterworks*
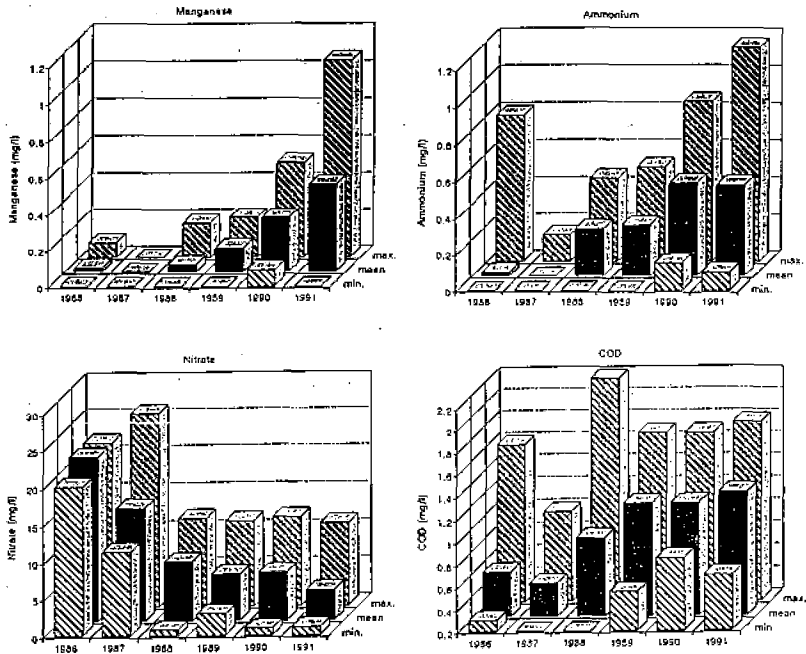
Figure 3.32: *Water quality of the bank filtration Ranay well, Nagymaros Waterworks*

3.6.4 HUNGARIAN EXPERIENCE OF YIELD REDUCTION

It has been noted above that extensive dredging has taken place below Nagymaros, in part in preparation for the Original Project. In consequence, the riverbed has dropped by 2.5 metres on average (Budapest Waterworks, 1994). This has led to a reduction in low flow water levels by 0.6 m at Budapest, 1.23 m at Nagymaros, and 1.5 m at Surány since 1960. The channel bed has become uneven, leading to the localised deposition of sediment, with consequences as discussed above. In the Budapest area, the thickness of filter media has decreased in places to 1-2 metres, which in practice means that it cannot perform its function properly. There has also been a decrease in the effective width of riverbed for filtration, by approximately 40-50 m or 30%. The estimated decrease in capacity due to reduced water levels is 100,000 m^3/day and due to decreased filter area is 200,000 m^3/day.

3.6.5 IMPACTS OF THE ORIGINAL PROJECT

3.6.5.1 Impacts of the Nagymaros Dam on bank-filtered wells in the backwater reach (Gönyü to Nagymaros)

The significance of bank-filtered wells in this reach has been discussed above. The existing well capacity is approximately 30,000 m^3/d, and potential additional resources have been estimated as 94,000 m^3/d (*Table 3.13* and *Plate 3.8, Volume 5*).

Changes in surface water quality can be expected, as discussed already in *Chapter 3.3*. However, a major concern is the process of sediment deposition, the subsequent degradation of organic matter, and the associated development of reducing conditions. As discussed above, there is ample evidence from international experience, including the Danube, and from Budapest, that these processes occur.

The processes of sediment transport are complex, and predictions are inevitably uncertain. In the case of the Nagymaros Reservoir, the influx of suspended sediment load will depend on the discharge from the upstream system of the Dunakiliti Reservoir, power canal and main Danube channel. Rákóczi and Bognár (1985) estimated that most of the upstream load would be transmitted to the Nagymaros Reservoir. More recent simulations (VITUKI, 1988) indicated that between 41 and 73% would be retained upstream, depending on the particular flow regime in a given year.

Apart from this input uncertainty, flows in the Nagymaros Reservoir would be affected by peak power operation, again leading to significant uncertainty in the estimation of the two-dimensional distribution of sediment deposition that could be expected.

The study by Rákóczi and Bognár (1985) suggested that the main section of concern was the 42 km-long section between Lábatlan and Nagymaros, although significant deposition further upstream could not be excluded. Consideration of the settling velocity of the fine sediment fraction, and the distribution of velocity profiles and bed shear stress expected during peak power operation led to the conclusion that fine sediment would mainly settle in a strip of 6.5 m depth below surface water level on each side with a combined width of 80 m at rkm 1708.5 and of 280 m at rkm 1724.4, upstream of Esztergom. The 1985 study estimated an annual rate of sediment deposition of 40-50 mm. Assumptions of a reduced sediment inflow suggest 20 mm/year.

Research by Starosolszky (1966, 1981) on the effect of sediment deposition on the reduction of infiltration rates indicated penetration of fine sediment within the alluvial profile. Hence the effects on reduction of bank-filtered well yields were estimated assuming:

A. a 5 cm. silt layer over the relevant strip

B. a 1 m clogged layer of alluvium underlying the silt

The potential reduction in yield was 2-6% in case A (which represents 1-2.5 years deposition) and 10-40% in case B, depending on well configuration.

To evaluate the groundwater quality impacts, László (1994b) modelled the redox processes in the filtration layer under conditions of organic degradation, i.e.:

– aerobic respiration

$$CH_2O + O_2 \rightarrow CO_2 + H_2O$$

– denitrification

$$CH_2O + \tfrac{4}{5} NO_3^- + \tfrac{4}{5} H^+ \rightarrow CO_2 + \tfrac{2}{5} N_2 + \tfrac{7}{5} H_2O$$

– manganese (Mn (IV)) reduction

$$CH_2O + 2MnO_2 + 4H^+ \rightarrow 2Mn^{2+} + 3H_2O + CO_2$$

– iron (Fe (III)) reduction

$$CH_2O + 8H^+ + 4Fe(OH)_3 \rightarrow 4Fe^{2+} + 11H_2O + CO_2$$
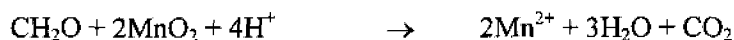
For a biodegradable organic content of settled sediment of 2% (VITUKI, 1988), sedimentation at the conservative rate of 2 cm/year and typical river water quality, it was concluded that reduction would occur, with the likely impact of increased iron and manganese in bank-filtered wells.

3.6.5.2 Impacts of the Nagymaros Dam on bank-filtered wells downstream

The national significance of the water supply from this reach *(Plate 3.9, Volume 5)* has already been discussed. It has been shown that dredging for the Original Project has, together with other dredging activities, already led to a dangerous reduction of the riverbed filter layer to 1-2 m in places, and that changing patterns of sediment movement have already given severe water quality problems, with certain parameters exceeding drinking water standards in excess of 2 orders of magnitude. In particular, construction of the Nagymaros coffer dam appears to have been responsible for the closure of wells due to unacceptable water quality. According to the Joint Contractual Plan, additional dredging was planned to lower the Nagymaros tailwater by 0.6-1.2 m.

The uncertainty in sediment transport calculations has already been referred to. A numerical modelling study of bed degradation downstream of the Nagymaros Dam used two alternative approaches, each well-founded on relevant Hungarian experience of the Danube (Bakonyi, 1994). Order of magnitude differences were obtained in the predicted bed changes, with local rates of degradation and aggradation of 1.5 m/year in the worst case.

The effects of the planned dredging were estimated to give a reduction in the yield of the bank-filtered wells of 75,740 m^3/d (Budapest Waterworks, 1994).

It is therefore evident that, although uncertain, predictions indicate a potentially serious threat to the Budapest water supply, and that adverse changes associated with the project have already occurred.

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CHAPTER 4

FLORA AND FAUNA

4.1 HISTORICAL DEVELOPMENT

by Gábor Vida

The area affected by the Gabčíkovo-Nagymaros project extends to the large area between Bratislava and Budapest. However, by far the largest impact is and will be on the unique inland delta, of which the Hungarian part is called the Szigetköz, and the Slovak part Žitný Ostrov. This area was originally covered with waterbodies, marshes and various kinds of forests ranging from inundated to the driest forest-steppe types. Due to the natural (flood) and artificial (clearing) disturbances, which started mainly in the last century, the diversity of habitats was supplemented by several succession series resulting in an exceptionally high species- and community-diversity. This high biodiversity was further increased by the transitional position of the area. Pannonian, East-Alpine (Noricum) and Carpathian elements of the flora and fauna meet here. The climate is also a mixture of continental, Atlantic and even sub-Mediterranean influences.

Agriculture has long taken over most areas of natural vegetation in the drier, less frequently inundated areas. In the middle of the last century, large scale river regulatory work started, confining the flooded area to the 2-6 km-wide belt (see *Chapter 2*) between the flood protection dykes. This first intervention did not change significantly the groundwater level distribution in the old (former) floodplain. Much more impact resulted, however, from the regulations to improve navigation. The originally braided channel was modified into the recent main channel plus side branches system, increasing up to 90% of the discharge in the main channel at the expense of the side-arms. This launched a series of slow gradual transformations (successions) in the floodplain.

4.1.1 PROTECTIONAL VALUE

In spite of all these anthropogenic actions, biologists have been able to report on an exceptionally rich flora and fauna (see *Plate 4.1, Volume 5*). As Mészáros and contributors (1994a, 1994b) describe, there are 80 different plant communities (associations) comprising one thousand vascular plants in the Szigetköz. Lower plants (mosses, liverworts, lichens, algae), fungi and micro-organisms are only imperfectly known.

The fauna is even richer (see Mészáros et al., 1994a, 1994b). The species so far recorded by zoologists (a few thousand taxa) make up only a fraction of the total fauna. In light of the rapid degradation of the habitats, it is questionable that the total fauna of the Szigetköz will ever be assessed.

Natural flooding was (until 1992) a major factor in maintaining high biodiversity. It excluded several otherwise competitive species in the floodplain, therefore supporting the survival of the specially adapted ones.

8% of the vascular flora of the Szigetköz are officially protected. There are 314 protected animals, of which 66 species are listed in the Hungarian Red Book. 9,158 ha belong to the Protected Landscape Area (Mészáros, 1994b).

It is well known that this area and, more generally, the inland delta are of international interest and have a patrimonial value (e.g. Dister, 1994). Until the last few decades, the Danube lowland between Bratislava and Győr represented the largest and most valuable floodplain in Central and Western Europe. The size of this area, namely the Szigetköz and the Žitný Ostrov, surpassed similar areas along the Rhine and Rhône rivers, and the latter were additionally altered by hydroelectric development. Szigetköz and Žitný Ostrov remain "especially important because of their morphodynamics but have been fundamentally destroyed by the construction of the Gabčíkovo-Nagymaros hydroelectric plant" (Dister, 1994). Concerning more precisely the Szigetköz, before the completion of Variant C, it was unique with respect to the diversity of its alluvial habitats, its geographical location, its geomorphic location, its geomorphological and hydrological features, and its sub-Atlantic climate. All these characteristics "lead to the development of combinations of species that partly differ from the usual fauna of European river valleys" (Mészáros et al., 1994b). The international patrimonial value of this area is well known and well documented (cf. Mészáros et al., 1994a).

There has been substantial damage in the flora and fauna as a consequence of the implementation of Variant C (see Mészáros et al., 1994a and Chapter 4.5). There can be no doubt for an ecologist that the loss so far recorded is only the first sign of a massive degradation. The whole process can take place over decades, giving the impression to the layman, accustomed to the rapid changes in the human spheres, that there is limited change. Short-sightedness, however, cannot be an excuse. The essential problem is that of gradual but cumulative losses.

According to the Rio Conference's recommendations, the "precautionary principle" should be applied in such a case: in the absence of adequate scientific knowledge large scale interventions should be avoided. This principle accords well with the experience of the ecological sciences.

4.2 THE NATURAL SYSTEM

by Gábor Vida

4.2.1 THE IMPORTANCE OF BIODIVERSITY

Natural terrestrial biotic communities, the interacting assemblage of thousands of living creatures (plants, animals, fungi and micro-organisms) have evolved for 400 million years, incorporating successful innovations and eliminating mistakes in the course of co-evolution. Only recently have we realised that even the present diminishing natural richness is still a rich storehouse. In addition, the natural systems contain invaluable information on principles of efficient organisation for energy utilisation and sustainable material use. Even more importantly, on a global scale we depend on ecosystem services provided mainly by natural ecosystems.

The major contrasting difference between natural and man-made ecosystems is in relative scales of biodiversity (Vida, 1994). Natural systems are rich in species (high species diversity), and each species is rich in gene forms (alleles) giving high genetic diversity, a prerequisite for long-term survival. On the other hand, man-made systems, e.g. an agro-ecosystem, are much more uniform in both species and genetic diversity.

Conservation and understanding of biological diversity therefore became a world-wide major issue the late 1980s in both the scientific and the popular press (Groombridge, 1992 and Wilson, 1988).

One of the most worrying issues confronting modern societies is the massive transformation of the Earth's landscapes taking place today, including changes in soil, water, vegetation, and atmosphere (Solbrig *et al.*, 1992). Present biodiversity changes have a negative influence on the biosphere's functioning. J.W.M. La Riviere from the International Institute for Hydraulic and Environmental Engineering (Delft, The Netherlands) regards biodiversity as "one of the most important problem areas of our time" for three reasons:

"1) It is the living part of creation, possibly unique in the Universe;

2) It is a storehouse of economic goods, underexplored and underexploited; and

3) It is an essential part of the life support system. Its complexity and vulnerability are poorly understood" (La Riviere, 1992).

Hence, as F. di Castri, President of IUBS (International Union of Biological Sciences) claimed, "Biodiversity is likely to become one of the most crucial issues of environmental sciences" (di Castri, 1990). Two years later at the Rio Summit (UNCED, United Nations Conference on the Environment and Development) the

Convention on Biological Diversity was signed by more than 150 states, including Hungary.

The Preamble of the Convention on Biological Diversity states as follows:

"Affirming that the conservation of biological diversity is a common concern of humankind,

Reaffirming that States have sovereign rights over their own biological resources,

Reaffirming also that States are responsible for conserving their biological diversity and for using their biological resources in a sustainable manner,

Concerned that biological diversity is being significantly reduced by certain human activities,

Aware of the general lack of information and knowledge regarding biological diversity and of the urgent need to develop scientific, technical and institutional capacities to provide the basic understanding upon which to plan and implement appropriate measures,

Noting that it is vital to anticipate, prevent and attack the causes of significant reduction or loss of biological diversity at source,

Noting also that where there is a threat of significant reduction or loss of biological diversity, lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimise such a threat,

Noting further that the fundamental requirement for the conservation of biological diversity is the in-situ conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings."

Again, this closely reflects the day-to-day experience of biologists and the lessons of their discipline. Consistent with this, the maintenance and safeguarding of the biodiversity in the Szigetköz and other affected areas of the Gabčíkovo-Nagymaros Project is an important national and international concern.

4.2.2. BIODIVERSITY LOSS IS UNAVOIDABLE WITH HYDROPOWER DEVELOPMENT

Natural ecosystems are among the most complicated natural systems. Despite much study, ecologists are still far from a complete understanding of this complexity. Natural ecosystems form an intricately interwoven system of the populations of plants, herbivorous and carnivorous animals, decomposers and the

non-living environment. Most of the living creatures of an ecosystem are invisible; in the gallery-forests of the Szigetköz there are several thousand species of which the conspicuous trees, game-animals, fishes and birds altogether represent only 1-2% at most. In the case of the floodplain ecosystems the river forms the core of the system. Its physical, chemical and biological parameters influence directly or indirectly every other part of the system. It is inconceivable to suppose that riverine ecosystems can be maintained by diverting substantial proportions of the water discharge from the main channel into an isolated power canal. Yet Miroslav Liška, a senior Slovak engineer, said in a recent report to New Scientist (Pearce, 1994): "We have separated the navigational and commercial function of the river from its ecological function. This gives us a unique opportunity to develop this section of the river in its natural form".

This artificially engineered "natural form" of the former river can at best be an artificial lacustrine ecosystem, if weirs are built, or an artificial small river if not. In any event, it would be far from performing the eupotamon functions described below (*Chapter 4.3.2.2*). What kind of ecological function of the river is left, if the flux is missing? The quoted scenario could be more or less valid only if 95% of the discharge remains in the main channel.

In the case of the implementation of the Gabčíkovo-Nagymaros Barrage System, the substantial loss of flora and fauna is inevitable for several reasons:

– Certain habitats are no longer available. Species adapted to these conditions (main channel with high water flow velocity) will disappear;

– With the changing water level and flow conditions many species find themselves in the wrong place, forced to move and recolonise to the nearest right place. Such has often been the case in an actively developing natural river system. The present Čunovo Dam situation, however, is quite different, for the magnitude of change was abnormally large (e.g. a 2-3 m drop in water level), and the natural and semi-natural spots now are mostly fragmented, separated by long distances, allowing little chance for many species to reach the suitable place;

– Even if they can find the correct place to colonise they have to compete with weedy species from the disturbed environment, and, having lost substantial genetic diversity through the "bottle-neck effect" of migration, they fail to establish themselves. Genetic diversity is necessary to adjust the population into the multi-species community's food web system (Vrijenhoek, 1994);

– Peak operation with huge daily fluctuation of the water level and flow velocity creates an additional burden and subsequent loss to the aquatic and littoral ecosystems (see *Chapter 4.4*).

4.2.3. PREDICTABILITY AND REVERSIBILITY

All these are basically stochastic processes: their time requirement and concrete realisation is highly unpredictable. A limited amount of disturbance can actually increase local biodiversity but usually only at the expense of regional biodiversity. In other words, new weedy species with ubiquitous distribution will enter the biotic communities and out-compete the unique local species or genotypes.

Thus, the final outcome, a loss of local biodiversity, is unavoidable. This has already been demonstrated by every single water regulation, including the Upper Rhine barrage system or the Rhône barrage system. P. Petermann (1987), an authority on Upper Rhine ecological impacts, concludes on the results of the two centuries of river transformations. "Altogether each intervention had adverse effects that made further measures necessary" (cf. Lösing, 1994). The most regrettable fact of biodiversity losses is that they are to some extent irreversible, particularly if they are induced by physical modifications of the habitat. As opposed to chemical disturbances or pollution, physical disturbances like dams are irreversible. Even if a locally lost species can be reintroduced from other places, the specific genetic composition will not be the same. Provided the colonisation was successful, hundreds of generations are needed to develop an adaptive gene pool comparable to that of the extinct, original population (Frankel and Soule, 1981).

4.3 ECOLOGY OF FLOODPLAINS

by Joachim Lösing and Albert Roux

4.3.1 INTRODUCTION

In the past ten years, the view of rivers as one-dimensional structures, primarily determined by the environmental parameters upstream and downstream, has progressively been enlarged to encompass other functional dimensions: the lateral dimension (riverine-floodplain interactions), the vertical dimension (surface water-groundwater interactions), and the time dimension of the interfering multi-scaled ecological to geohistorical processes (Amaros *et al.*, 1987). We will focus here on the lateral dimension of river-floodplain systems.

The determining ecological factor of floodplains is the cycle of flooding and drying. Otherwise, the whole ecosystem with its typical floodplain forests and other types of biotopes could not exist. Floodplains are extensive amphibic ecosystems in contrast to other types of wetlands.

hydro-dynamics	**morpho-dynamics**
periodicity and amplitude of water level and depending water table fluctuations.	series/course of erosions, transports and sedimentations (formation of bank failures, gravel banks, embankments, and loamy toplayers)

pedo-dynamics
micro relief and texture conditioning soil genesis; dynamics of the soil water and soil air balance; import of nutrients (and pollutants)

bio-dynamics
evolution (self-organisation) of floodplain biocoenoses and succession

Figure 4.1: Processes of natural floodplain dynamics responsible for the variety of structures (Henrichfreise, 1988, modified in Lösing, 1994)

The periodicity and the amplitude of water level fluctuations in the reaches and the inundation area are determined by hydrodynamics, the specific water discharge regime of a river (*Figure 4.1*). Running water produces erosion, transport, and deposition, i.e., morphodynamics. Morphodynamics result in soil genesis, soil-water dynamics and soil-air diffusion, known as pedo-dynamics (including dynamics of other substances like oxygen, nutrients and pollutants; see *Chapter 3*). Lastly, hydrodynamics and morphodynamics are controlling all ecological processes. In addition, the topography of the inundation area and the conductivity of all stretches for irrigation and drifting biota are of particular importance.

4.3.2 THE ECOLOGICAL ZONATION

4.3.2.1 Landscape ecological zonation

A mosaic of structures, typical in a floodplain, arises from the combination of all processes, with varying impact from place to place. Nevertheless, the structures may be differentiated following the generally acknowledged ecological zonation (Henrichfreise, 1988):

a) Surface waters of the floodplain and river banks

Surface waters of the floodplain are subdivided according to the period of water discharge (permanently to episodically filled with water), the intensity of the current (fast flowing to stagnant) and the morphology, or form, of surface (narrow, broad and deep, shallow). River banks are subdivided by inclination (steep to

gentle slope), substratum (silt to gravel), and duration of the terrestrial and amphibian phases.

Lower zones of the floodplain (wet to moist)

b) Softwood and lower hardwood floodplain

The softwood floodplain is subdivided according to the intensity of hydro- and morphodynamics. *Dynamic* softwood exists in areas near the river with strong erosion and deposition. *Wet* softwood exists in areas distant from the river, situated on a higher level with little influence of erosion and deposition). The *lower* hardwood floodplain is differentiated by shorter duration of flooding, depending on the relief and granular fine soils.

Upper zones of the floodplain (fresh to moderate dry)

c) Upper hardwood floodplain and transition zone

The zones are differentiated first by the duration of floods, which depends on the relief. Second, the combination of fine deposits and the depth of the upper soil layer characterise the upper zones. Inundation is relatively brief but periodical in the upper hardwood floodplain. In the transition zone, inundation is brief and episodic. Due to human impact, such as embankments and dams, another zonation has to be introduced:

Active floodplains

Today, human activities divide the floodplain into two ecologically distinct areas. The sections of the original inundated areas which are situated within the embankments are the active recent floodplains. Floods, corresponding groundwater-table fluctuations, and the four dynamic processes (hydro-, morpho-, pedo- and biodynamics; see *Figure 4.1*) are responsible for their existence and variable changes, though river regulation and bed degradation, the latter mainly caused by dredging (see *Chapter 2.2*), have already altered the dynamics of the system to a certain extent.

Old floodplains (protected side of the floodplain)

The sections of the original inundated areas which are protected from floods by levees or dams are called old floodplains. They originate from natural floodplains but lack the determining factor. The influence of a fluctuating groundwater-table which corresponds to the water level of the river, although reduced, is the only one remaining. Side branch systems with stagnant water belong to this category. Geographically, these side-arms are still part of the floodplain; ecologically, they

are no longer an integral part of the floodplain system. Instead, they resemble a lacustrine environment with stagnant waters, such as lakes, marshes, and other types of wetlands.

4.3.2.2 The floodplain waterbodies

The typology of floodplain waterbodies in the Szigetköz can be summarised as follows, recognising 4 main types of functional sets (*Figures 4.2* and *4.3*):

– Eupotamon: the main channel of the river, the meandering sections and its anabranches (braided zone) with a permanent unidirectional flow. The bottom is composed of stones and gravel. There is no stratification in temperature or oxygen. There is an absence of macrophytes. Zoobenthos is dominated by rheophilic species with limited abundance and low biomass. Fish community is characterised by rheophilic species, open substratum spawning species, and little ichthyomass;

– Parapotamon: the side-arms of the braided zone are permanently connected with the main channel at their downstream ends. The flow, which is fed by both surface and groundwater, may reverse due to water level fluctuations in the main channel. The bottom is composed of gravel mixed with sand and silt. Vertical stratification of temperature and oxygen content may appear. Macrophytes are scarce but phytoplankton is abundant and rich in biomass. The fish community is rather diversified and the ichthyomass moderate;

– Plesiopotamon: permanently or temporarily stagnant waterbodies that were formerly side-arms in the braided belt. They are sometimes fed by groundwater. Their size increases or decreases according to the hydrological conditions. The bottom is silt and clay. Vertical stratification in temperature and oxygen content exists. Dense groups of macrophytes and phytoplankton are diversified and very abundant. Zoobenthos and zooplankton have a high biomass. Fish communities are mildly diversified, and ichthyomass varies from very low to very high;

– Paleopotamon: permanently stagnant waterbodies, oxbow lakes, very rarely inundated by flood. The bottom is silt and clay. There is important stratification of temperature and oxygen content. Macrophytes are very dense, and phytoplankton very sparse. The biomass of the zoobenthos is low. Fish communities have few species, and ichthyomass is rather high.
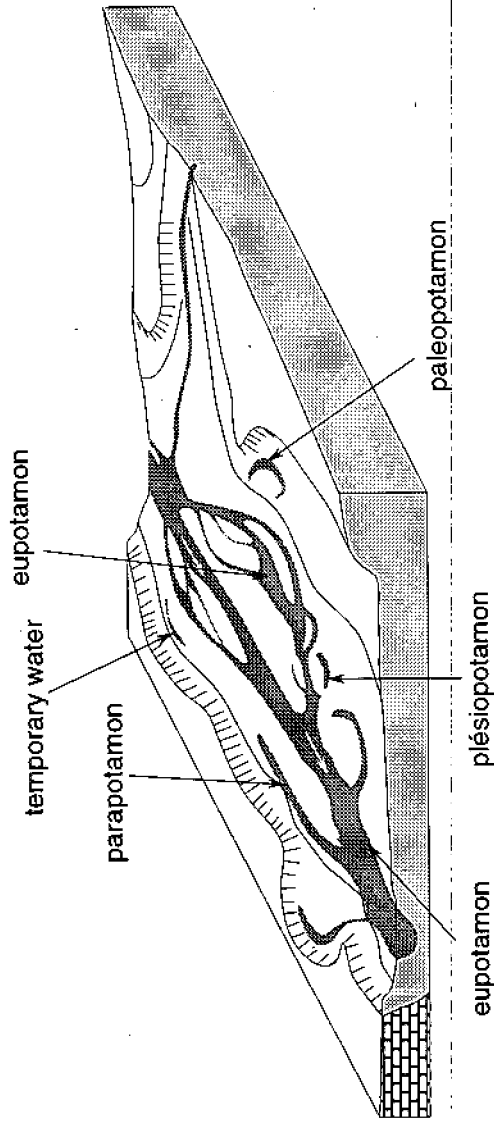
Figure 4.2: *Main types of waterbodies in a natural system (schematic figure)*
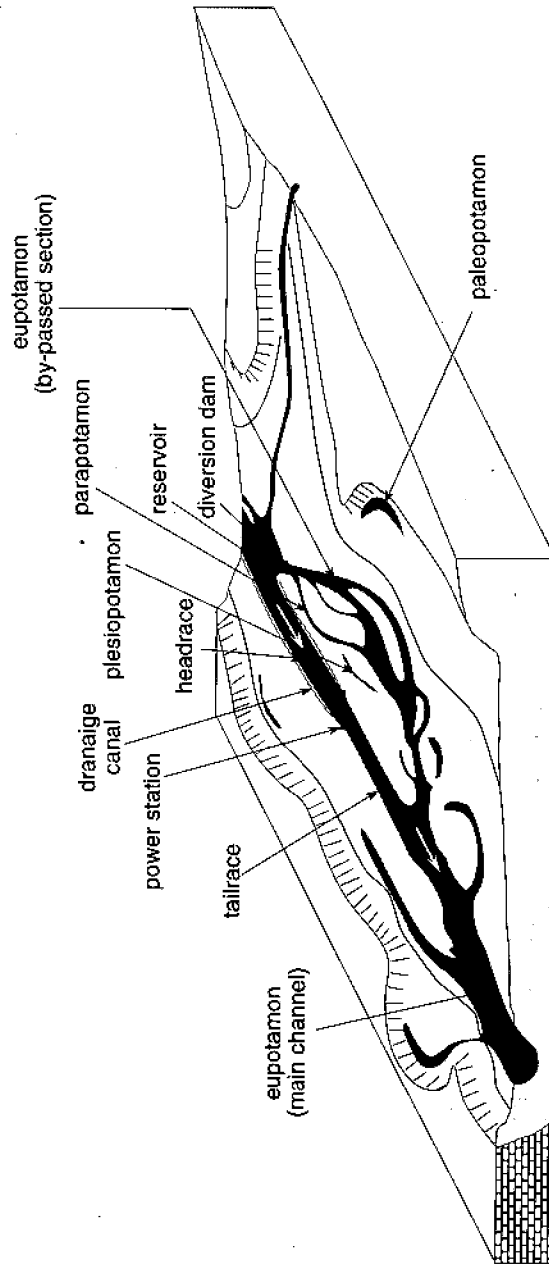
Figure 4.3: Main types of floodplain waterbodies in a regulated system

4.3.2.3 The various biocoenoses of floodplains

The following description is based on the natural morphological formations and follows *Figure 4.4*.

In surface waters, flowering plants and aquatic macrophytes, submerged or with swimming leaves, represent the vegetation. Here, the continual existence of open water is required. During average fluctuations of water levels, pioneer communities (algae and lichen) coexist with reeds on non-wooded, amphibian shores (ecotones). The water level fluctuates frequently and periodically.

On the bars and islands, bushy willow stands grow, eventually followed by willow trees and poplars, grouped in dynamic softwood riparian forests. Under typical conditions, they exist on a low level, only slightly above the average water level. The vegetation is submerged by flood water up to 5 months a year on average (in Central Europe). Under extreme climatic events, inundation occurs only 3 weeks or up to 9 months. Ashes and alders are the main species of the wet varieties of softwood and lower hardwood riparian forests. Elms and oaks dominate the more common dynamic parts of the hardwood forests. These dynamic parts are connected to the upper hardwood riparian forests on higher ground, which consist of a large variety of species, especially elms and oaks. A transition zone , usually containing deciduous forests with elms, oaks and hornbeams, is flooded only episodically or exceptionally during a few days per year. The highest elevations of the floodplains consist of a gravel substratum which carries specific vegetation communities adapted to a very dry and rather hot environment. They are called "steppe forests and meadows" along the Danube and "Heisslaende" ("hot lands") in Austria and "Brennen" ("burners") in Germany.

The most important determining factors for the vegetation are duration of inundations and the elevation of the groundwater-table during the vegetation period. It should be remarked that the zonation is not an absolute, but only a relative division based on the altitudinal levels. It is subtly diversified by the different levels, frequencies, and durations of floods; by the soil texture; and by the current. The fluvial processes of erosion and deposition interrupting the genesis of soil is responsible for the existence of softwood riparian forests on the same level as old hardwood forestlands. The appearance of many formations side by side in immediate vicinity and in different steps of succession is typical.

exceptional high waters
average level of high waters
average level of waters in summer
low waters
gravel
alluvial loam
30 m
3 m

annual herbaceous	bushy willow stands	mixed oak and elm	deciduous forest
prostrate herbaceous			
shore reedbed	white willow stands	grey alder	
non-wooded floodplain	softwood forests	hardwood forests	

azonal vegetation   zonal vegetation ⟶

Figure 4.4: Distribution of plant formations on a cross-section of the middle reaches of an alpine foreland river (from Ellenberg, 1976, modified in Yon and Tendron, 1981)

In addition, rare, catastrophic events, such as ice drifts blocking the channel and causing extraordinary floods, create further formations of bare soils and rough pioneer areas on all altitudinal levels.

Furthermore, activities of animals such as beavers and ruminants (herds of wild cattle, horses and deer) create and maintain open land, leaving meadows, pastures, forest edges and brushes or beaver ponds. Man has also been part of the ecosystem since the glacial epoch, cutting trees to gain arable land, pastures and wood. Due to the large number of biotopes, the dynamics related to inundations, and the resulting various stages of plant and animal composition, the floodplain ecosystem contains the largest variety of species outside the sea and mountains (see *Chapter 4.1*). Accordingly the species have adapted uniquely to the various sections of the floodplain.

Highly specialised species are to be found in the lower zones where an excellent adaptation to extreme factors is necessary to survive. Environmental conditions

change more quickly and more often than in other systems. Thus, organisms must use pioneer strategies to settle new sites. They can reach new sites, passing large distances, either actively or passively, such as seeds which are transported by water. Many species need special sites. For instance, tamariscs and wading birds need gravel bars, and kingfishers or sand martins need the native, steep slopes of bank failures for breeding. Many willows, on the other hand, have a large spectrum of sites on which they may proliferate, if they manage to compete successfully against other woody species. Only in floodplains do they prevail since they endure long-term inundations up to 300 days/year (100-190 days/year on average). The beaver and many birds, such as the black stork and osprey, have long-range habitat demands and prefer undisturbed places for nesting on islands or in natural forests.

Fish and invertebrates depend on permeable and undisturbed migration routes to their spawning grounds, which for many may only be found in the floodplain.

4.3.3 BIOLOGICAL FUNCTIONS OF FLOODPLAINS AND RIVER-FLOODPLAIN INTERACTIONS

We try here to summarise the main biological functions of floodplains and floodplain-river interactions in order to identify the losses that are caused by alterations of river systems and to provide a scientific rationale for conservation. Four main biological functions can be identified:

- the nutrient cycle and water quality;

- the organic matter cycle and the biomass production;

- the life-cycles of aquatic species and the maintenance of communities;

- the biodiversity.

4.3.3.1 The nutrient cycle and water quality

The complexity of the processes interacting in the floodplain makes the identification of its role as source or sink for mineral nutrients difficult. Flood waters bring substantial amounts of nutrients to the floodplain. They fuel plant growth and are responsible in part for the high nutrient level of alluvial ecosystems. The uptake of these nutrients by floodplain vegetation provides a purification mechanism for the surface water of the river.

Regulation of a river and its floodplain affects the water quality mainly by changing the water temperature and the ions correlated with primary production. Reservoirs in the main channel act as thermal regulators due to the great quantity of water and the decrease in short-term and seasonal fluctuations. These reservoirs also trap nutrients and sediment, including suspended, particular organic matter.

The transport of nutrients, especially nitrogen and phosphorus, is often blocked in reservoirs. The physio-chemical dynamics of a regulated river are essentially controlled by the parameters of the reservoir, such as storage capacity and the position of the water outflow and by its function, such as a deep release (hypolimnial) outflow or underflow mechanism. In the Mississippi river, during low flow, some authors note autochtonous nitrogen and phosphorus inputs from side-arms and former channels to the main channel (Fremling *et al.*, 1989). During floods, the physio-chemical composition of the dead side-arms and the main channel are similar. Regulation directly influences the chemical composition of the main channel, but, according to the exchanges between this channel and the other floodplain waterbodies, the water quality of the floodplain environments will also be affected. These floodplain waterbodies will nevertheless act as refuges for the fauna of the river during disturbing events, such as chemical and toxic pollutions.

4.3.3.2 The organic matter cycle and the biomass production

Fluvial wetlands appear to be among the most productive ecosystems. Two conditions can explain this productivity. First, abundance of land-water interfaces characterise these systems; such interfaces prove to be the most productive zone along land-to-water gradients. Second, the fluctuating nature of these boundaries ("moving littoral") promote a very active mineralisation and recycling of the organic matter, resulting in a higher productivity than in more stable aquatic or terrestrial conditions (Junk *et al.*, 1989). Preliminary data on floodplain forests of the South-East coast of the United States show (Cuffney, 1988):

- the processes of the organic matter cycle enriches the riverine-floodplain environments. The floodplain introduces organic matter to the river. These inputs outweigh the primary production of the river and are of the same order as inputs from the upstream watershed. They are important because they provide a substantial food source sustaining the riverine communities;

- The floodplain also regulates the organic matter cycle. The coarse organic particles are retained by snags, slowing the losses by downstream exportation. The major release of organic matter to the river (i.e., the autumn litter) is usually postponed until the spring flood.

Research carried out on the Slovak side of the Danube floodplain also provides useful information. Numerous measurements of the phyto- and zooplankton productions in the Danube side-arms provide evidence of the very high productivity of these biotopes and their contribution to the productivity of the main channel. The biomass and primary production of the main channel are greatly influenced by the fauna (plankton, macroinvertebrates, fish juveniles) and nutrients inputted from the side-arms and former channels (Ertl, 1985 and

Vranovsky, 1974, 1985). Studies of the Upper Mississippi river and the Rhône river elaborate their roles as producers and subsequent distributors by their drift.

The fish production of the floodplain waterbodies is highly correlated to the periodic flooding. Numerous studies carried out in the braided side-arms of the Danube give figures and estimations concerning this subject. These studies show the importance of dispersion from the side-arms to the river during high waters and the subsequent shelter in former channels and lentic waterbodies for fish which did not drift (Holčik and Bastl, 1973; Holčik *et al.*, 1981 and Holčik, 1988, 1991). Parapotamic and, to a lesser extent, pleisopotamic waterbodies are of special interest in this respect. Maintaining the connection with the river is very important for production. If waterbodies are excessively isolated and sporadically flooded, their biomass and production are low. Studies of waterbodies in the Rhine and Rhône floodplains which are permanently or only temporarily connected with the river prove that higher biomass and diversity occur in permanently connected bodies (Lelek, 1989).

4.3.3.3 The life-cycles of aquatic species and the maintenance of communities

As in the case of fish, the known migration patterns of two mayfly species (*Leptophlebia cupida* in Canada and *Parameletus chelifer* in Sweden) provide clues that floodplain water in bodies connected to the main channel are vital stages in the life cycle of some invertebrate species. For these mayflies, the aquatic floodplain biotopes provide a temporary shelter from severe flow conditions in the main channel and better temperature and food which accelerates growth (Hayden and Clifford, 1974 and Olsson and Söderstrom, 1978). When the main channel returns to normal after a severe disturbance (such as floods shifting the bed sediment), side channels and temporarily inundated areas provide potential sources of organisms for the recolonisation of the main channel. This phenomenon is documented by a study of post-flood invertebrate drift in a side channel of the Durance river in France (Prevot and Prevot, 1986).

The diversity of aquatic and semi-aquatic habitats is necessary for the life cycle of numerous fish species and for refuge during disturbing events such as floods, reductions of discharge, or polluting inputs. The example of a toxic pollution of the Rhine in November 1986 can be given (Müller and Meng, 1990). The recolonisation (resettling) of the main channel by fishes was quicker than expected because many fish found shelter in the few remaining or rejuvenated side-arms and in the tributaries still connected with the channel. The periodic phenomena such as floods, low flows, or physio-chemical cycles are essential to normal, productive biological functioning of the floodplain. The necessity of these conditions can be exemplified by the migration of fish in a sector of the Morava river's floodplain.

4.3.3.4 The biodiversity

Biodiversity of benthic invertebrates in different aquatic environments

Floodplain aquatic and semi-aquatic ecosystems support rich and diverse communities. They encompass the whole range of aquatic conditions from flowing to stagnant to semi-aquatic waters. Two cases can be exemplified from the Rhône floodplain. In the first one, a parapotamic side-arm, two opposing flows enter a former channel. Upstream, water seeps into the channel from the river. Downstream, the side-arm is directly connected with the main channel, and therefore feeds the channel during low flow, whereas during floods the channel feeds the side-arm. Thus, within a two kilometre stretch of the former channel, a clear gradient from a spring to fluvial condition exists. This results in a strong gradient structure of benthic *Oligochaetes* communities with local overlapping of phreatophilous, rheophilous and lenitophilous species (Juget and Roux, 1982).

In the second case, the large amplitude of hydrological fluctuation in a set of former meanders of the Ain river, France, provides the optimal conditions for the short-term coexistence of ecologically distinct aquatic beetle assemblages (Richoux and Castella, 1986). This type of diversity can be described by the "intermediate disturbance hypothesis" (Ward and Stanford, 1983), which states that the productivity of the system and the coexistence of otherwise competitive species is enhanced by the diversity of ecosystems undergoing intermediate levels of disturbances (in this case, floods or drought conditions). A traditional example can be given of the diversity of former channel types in a floodplain sector supporting a large range of invertebrate communities in the surface water and the groundwater (Dole and Chessel, 1986). The lack of objective and comparative methods to evaluate the biological and functional diversity of floodplain systems should be emphasised. It is especially difficult to relate this parameter to different taxonomic characters or to make comparisons for different wetlands undergoing various types of human alterations. The physical factors of a regulated hydrosystem determine the ecology according to the quality, quantity, and stability of the benthic invertebrate communities. Different studies in the Missouri (Morris *et al.*, 1968 and Hesse *et al.*, 1989a, 1989b), Mississippi (Becket *et al.*, 1989), Rhône (Cogerino, 1989 and Fruget, 1991) and Volga (Mordukhai-Boltovskoi, 1979) rivers show that species diversity is greater in unembanked parts of these rivers than in embanked ones. Embankments lead to a reduced diversity of substrates (habitats), limiting biodiversity. The banks, ecotones between terrestrial and aquatic (interstitial and potamic) environments, play a very important role in the processes of colonisation. The vegetal and mineral habitats of eroding environments which are connected permanently to the river (lotic side channels, wing dykes and embankments of the main channel) have more individuals than mineral habitats of silting environments and vegetal semi-terrestrial habitats. This indicates the evolution of the waterbodies towards terrestrial stages by siltation.

Biodiversity of fish in different aquatic environments

The taxonomic diversity of fish increases from upstream to downstream as a function of the diversity of habitats, i.e., as the floodplain increases. The positive correlation between structure of fish communities and an increase in stream order is used to indicate geomorphological and hydrological changes along the longitudinal continuum. The structure of fish communities can also reflect disruptions in the hydrosystem (disappearance of backwaters and former channels, disappearance of islands and shingle-shores). This is demonstrated by examples from highly regulated rivers in the United States, such as the Missouri (Hesse *et al.*, 1989a, 1989b), Colorado (Stanford and Ward, 1986), and Tennessee (Krenkel *et al.*, 1979) rivers. In these rivers, numerous native original species have been replaced by exotic species as well as littoral and pelagic planktonophage species which usually constitute a minor part of fish assemblages in unmodified reaches. In European regulated rivers, such as the Rhône (Persat, 1988 and Fruget, 1992), Rhine (Lelek, 1989) and German-Austrian Danube (Balon *et al.*, 1986), the fish communities are dominated by some species which represent 80% or more of the absolute abundance. The structure of these communities has shifted from phytophilic (floodplain) spawners to mainly lithophilic (main channel) spawners and limnophilic *Cyprinids*, clearly indicating a lower value with respect to nature conservancy. Thus, the species diversity of fish is closely correlated to habitat complexity. The more diversified and accessible the aquatic and semi-aquatic areas are, the more variable is the structure of communities and the more diverse the species. The same principle applies to the benthic invertebrates.

4.3.4 CONCLUSION

Fluvial wetlands and floodplain waterbodies are generally more productive than the running water of the main channel. When floodplain habitats are connected to the river, a major part of the organic matter is washed out into the running water, providing food for the benthic invertebrates and the river fish. These connected habitats are also used as spawning areas and nurseries as well as a refuge during high spates or accidental pollutions of the main river by numerous fish species from the river.

However, floodplain waterbodies and wetlands are processed by natural phenomena (ecological successions, eutrophication, siltation) which transform them into terrestrial habitats in a more or less short term sense (from several decades to a few centuries). The connections between floodplain environments and the main river also experience temporal changes. Seasonal and annual fluctuations on the connection with the main channel depend on the water level of the river as well as the morphology of the channels, alluvial plugs and bank levees. On longer time-scales, changes of the degree of connection result from human impacts as well as natural processes (ecological successions, siltation). Some of these processes are reversible, naturally or artificially. The process would be naturally

reversed if the fluvial dynamics (lateral erosion) can reset the ecological successions and reconnect the former channels to the river. The connections could also be artificially restored (restoration concept). Considering the functional dependency of the diverse habitats of river floodplains and their ability to restore themselves, any environmental management scheme should take into account the different spatial dimensions of the fluvial hydrosystem (running to stagnant waterbodies, wetlands, terrestrial biotopes, underground alluvial biotopes) as well as the temporal dimension (genesis of the diverse biotopes, successional processes, changes in connectivity). To be applied, these dimensions must be quantified.

4.4 IMPACTS OF THE ORIGINAL PROJECT
by Joachim Lösing and Albert Roux

4.4.1 CONSTRUCTION

In order to avoid repetition, the effects will be separated into short-term and long-term impacts, the latter being evaluated in the operation section. Nevertheless, all impacts will be discussed in *Chapter 4.4.2.*

4.4.1.1 Dunakiliti-Hrušov Reservoir

The Dunakiliti-Hrušov Reservoir was envisaged with a size of approximately 60 square kilometres, including the head race canal. This element of the Original Project has already been realised. All the aquatic and floodplain structures except the main channel have been destroyed by gravel excavation, construction of the dyke and the canal or by other measures; all forests have been cleared, and all other vegetation has been removed within about 6,000 hectares.

The Original Plans had counted on taking about 6 months to fill the Dunakiliti Reservoir, while the waters on the floodplain and on the protected side branches downstream in the Szigetköz would have received a continuous water supply. However the riverine and floodplain ecosystem needs much more time to adapt, despite the fact that this type of ecosystem is able to react faster than other types (like beech forests and other zonal systems; cf. Lösing, 1994), utilising inherent means of reproduction after catastrophic events.

4.4.1.2 The Szigetköz

Under natural conditions those catastrophic events, mentioned above, are very rare and do not affect a complete ecosystem, such as the Szigetköz with about 375 square kilometres, not to mention the area of the Slovak Žitný Ostrov. In addition,

there are usually undisturbed areas upstream and downstream where any form of re-population can start from. In this case, however, the section of the Szigetköz would have been locked as an isolated island between the impoundments of Dunakiliti and Nagymaros, developing lacustrine rather than riverine biotopes.

Because of the long history of river training and works in advance of the project, some of the anticipated damage has already occurred. Due to extensive gravel dredging around Bratislava the riverbed of the main channel had degraded drastically (see *Chapter 2.2*). The corresponding groundwater-table had dropped as well.

As a result of the relatively fast filling of the upper reservoir which was envisaged, all the vegetation types in the Szigetköz, influenced by the groundwater, would have been damaged by the extraordinary water shortage. For the vegetation as well as the fauna depending on it, the water regime of the surface soil-layer in combination with the floods is the most fundamental factor (Lösing, 1994). The drop of groundwater-tables together with reduced inundations would have caused severe problems in the water balance of the plants. Specifically, these changes would have threatened the softwood riparian forests of willow and poplar in this area (Mészáros *et al.*, 1993). Willow woods "used to give a nearly continuous cover on the islands of the Szigetköz-Danube labyrinth until the 1920s" (Simon *et al.*, 1993). Partially they had to give way to the timber plantations, mainly in the central parts of the islands. Nevertheless, the remaining woods indicated in 1991 were still in "better conditions than indicated by data collected by Kárpáti in the 1950s from willow woods outside the Szigetköz" (Simon *et al.*, 1993).

4.4.1.3 The Nagymaros Reservoir and its downstream section

The 123 km-long reservoir, including the Danube Valley upstream of Nagymaros, would have radically changed ecological conditions. This section of the Original Project would have required the reinforcement and extension of dykes along both banks of the Danube to contain the water fluctuations resulting from peak power operation. The construction of the reservoir levees would have wiped out the dry meadows on top of the previous dykes as well as parts of the narrow strip of recent, active floodplains within the embankment.

The intended lowering of the riverbed downstream of Nagymaros would have degraded the riverbed by 0.60-1.20 m on average (see *Chapter 2.3*). Considering the findings of the MaB[1] ecosystem study at Altenwörth, Austria (Hary and Nachtnebel, 1989 and Lösing, 1994), the corresponding drop of water levels by only about 0.50 m caused already negative effects to the vegetation of that particular stretch of the Austrian Danube. Similar impacts are to be expected at this section of the project.

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[1]   Man-and-Biosphere program of the UNESCO

4.4.2 OPERATION

4.4.2.1 General impacts on the aquatic biotopes

According to Holčik et al. (1981), the waters in the entire section affected by the scheme covered about 7,937 hectares prior to the construction.[2] The bands, delimited by the water-level variations (the ecotone of the littoral zone), extended over approximately 671 hectares. The surfaces between the littoral zones (the medial zones) covered 7,266 hectares. None of these areas would have remained in their previous condition since hydrologic parameters would have changed everywhere.

The benthos communities of the riverbed would have been destroyed in all the sections where the bed would had been deepened by dredging or other measures, such as the construction of dams, coffer dams, dykes or "underwater weirs". The reduced discharge by the upper reservoir during the filling would have caused further damage to the other aquatic biotopes suffering from water shortage as a result of the induced riverbed erosion.

Those detrimental effects have been mentioned by the Slovak hydrobiologist Holčik and contributors (1981):

"We may now conclude by stating that after the completion of the GNRBS project, the entire Danube section stretching between Bratislava and Nagymaros will have only a minimum biological importance, and moreover the fish populations of both the lower and upper Danube sections can be expected to show considerable decreases. The principal negative influence of the GNRBS is that the conception of the project with a diversion canal eliminates the very floodplain which, together with the arm systems, makes up the productive base of this region and also acts a sort of biocenotic centre as well, which determines to a considerable extent the population of the main channel by all aquatic organisms."

4.4.2.2 Dunakiliti-Hrušov Reservoir

In the upper reservoir the benthic biomass would have been about 30 times higher compared to the previous conditions in the main channel, primarily *Oligochaetes* (Holčik et al., 1981).

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[2] This figure given by Holčik et al. (1981) is probably far too low. It would just account for the Danube itself between Bratislava (rkm 1870) and Budapest (rkm 1650) considering an average width of 360 m. Thus the side branches on both sides of the river are not included.

Several million tons of sediment per year were expected to be deposited in the reservoir (see *Chapter 2.2*). These sediments play an important role in the functioning of the natural, undisturbed ecosystem by silting up in the floodplain, providing it with nutrients and producing physical stress to the plants. Above that, this sedimentation induces the growth of the typical species, adapted to these conditions, and prevents other species from settling in this area. By retaining the sediment in the reservoir, this abiotic element would be reduced significantly. Similar results would have occurred in the riparian ecotones downstream of the Nagymaros barrage.

4.4.2.3 The Szigetköz

The annual average discharge of the Danube was approximately 2,000 m^3/s. Under the Joint Contractual Plan, this was to be reduced to 50 m^3/s. It was envisaged to release up to 200 m^3/s discharge in case of necessity during the growth season without further specifications. Reductions of this order (85-97% of average flow) would have lowered the surface water level, reduced the areal extent of surface water and thus caused a drastic decrease of the groundwater-table. The levels were expected to drop by up to 3 metres, especially in the central part of the Szigetköz. A smaller but still very significant drop in the groundwater level of up to 2 m was forecast for the protected area outside the dyke system.

According to the Original Project, which did not entail mitigation measures at its conception, the bed of the Old Danube and the Slovak and Hungarian side-arms would have lost approximately 58% of its aquatic habitats, a total of 1,085 hectares (Holčik *et al.*, 1981).

For the fish fauna three general changes have been predicted (Holčik *et al.*, 1981):

– changes of the species composition;

– disappearance of more sensitive species (like *Salmonids*);

– replacing by species of lower sensitivity (*Cyprinids* like Roach and Chub).

Similar developments could be expected for the whole flora and fauna. Hence a considerable deterioration of the natural value of the Szigetköz would occur.

Silty sites and banks

The aquatic macrophytes, the moss cover on the gravel, as well as the riparian plant communities living on silty sites, and the willow brush would become extinct in the entire affected area. Once exposed to the air by the radical drop of the water levels, they would have been completely eliminated within a short period. The

general decline of the water level would have resulted in the rapid expansion of weed communities. This is particularly striking in the main channel in the Szigetköz (Mészáros *et al.*, 1994a).

Interruptions of connections

As a result of the diversion into the bypass canal, the connection between the previous main channel and the branch system in the recent, active floodplain would have for the most part ceased to exist. The diversity of this braided zone was the most important conservational factor for the survival of several species in the main channel. Therefore, the diurnal and seasonal migrations between these two parts of the aquatic system in the upper section of the Szigetköz would have stopped. This fact would cause a decline in the populations, particularly in the long term (Mészáros *et al.*, 1994a).

The old floodplain (the protected side) in the Szigetköz

The decline or gradual disappearance of the populations in the oxbow lakes, canals and ponds would have been more rapid than in the active floodplain inside the inundation dykes, because the artificial water supply would have been even less effective in these biotopes. As a direct result of the diversion, the water would have practically disappeared in the oxbow lakes. Therefore, their fish fauna would mostly have been killed out. The chance for a natural repopulation would have been minimal (Mészáros *et al.*, 1994a).

Experiences of ecological impacts at the Upper Rhine

Fundamental changes in the area of project would be expected in all the riparian forests and vegetation, except perhaps those small elevations with steppe forests which have not been inundated (at least not in recent decades). Many floodplain ecosystems of other rivers have experienced similar damage and destruction caused by river regulation and waterpower development. The example of the Upper Rhine between Basel, Switzerland, and Rastatt, Germany, is appropriate, especially as it was used to show the environmental benefits of the Gabčíkovo-Nagymaros Project.

At the Upper Rhine three steps of river training have been carried out since the beginning of last century (see *Plate 3, Volume 1*). Every stage of the regulation works was accompanied by unexpected, serious, adverse effects which were meant to be corrected with the next measure; nevertheless, other economic and ecological

damage occurred.[3] Therefore, France and Germany decided to break the vicious circle of correcting the negative impacts of a barrage by building another one further downstream and opted for a small-scale solution with the controlled addition of riverbed material (see *Chapter 2.6.1*). Furthermore, about 10 years ago a large programme was started at the Upper Rhine to restore floodplain habitats which were damaged or lost by the implementation of the Upper Rhine barrage system. The programme combines flood protection measures with ecological restoration and is called "Integrated Rhine Program" (LfU, 1994 and RP Karlsruhe and Freiburg, 1990).

The impacts of hydropower development at the Upper Rhine were disastrous for flora and fauna. At parts of the 70 km section of the full diversion, 81% of the alluvial forests were devastated or dead. In the section partially diverted only some typical vegetation and their fauna survived within the inundation dykes though with considerable change in composition of species. In the section of river barrages (phase 3 on *Plate 3, Volume 1*), the entire floodplain ecosystem was excluded from floods. Most of the vegetation (85%) changed from being typical and adapted to the ecological conditions of a floodplain to being unadapted and uninfluenced by groundwater. In none of the regulated sections of the Rhine[4] could the natural unique vegetation and wildlife be preserved. The new communities are significantly less valuable from the ecological and conservational point of view (Hügin, 1980, 1981; Dister *et al.*, 1990; Hügin and Henrichfreise, 1992 and Lösing, 1994).

At the Upper Rhine, the predominant plant communities of the lower and upper hardwood riparian forests, belonging to the elm-ash-oak forests (*Querco-Ulmetum minoris* Issl. 24), are replaced by those of the oldest and uppermost levels of the floodplain, belonging to the oak-hornbeam forests (*Carpinion betuli* Issl. 31 em. Oberd. 57) and no longer being influenced by groundwater. The influence of floods has become negligible as well. Due to the long life-cycle of woody species, the conversion of the forests is still in process, but the characteristic species of the herb layer have manifested the change.

Predictable changes in the Szigetköz

The impacts of the Original Project on the wetland habitats of the Szigetköz would be quite similar, though their species composition is slightly different (*Figure 4.5*).

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[3] Similar effects have been observed for example at the Rhône river (Fruget, 1992).

[4] (the sections of full and partial diversion as well as the section of barrages)
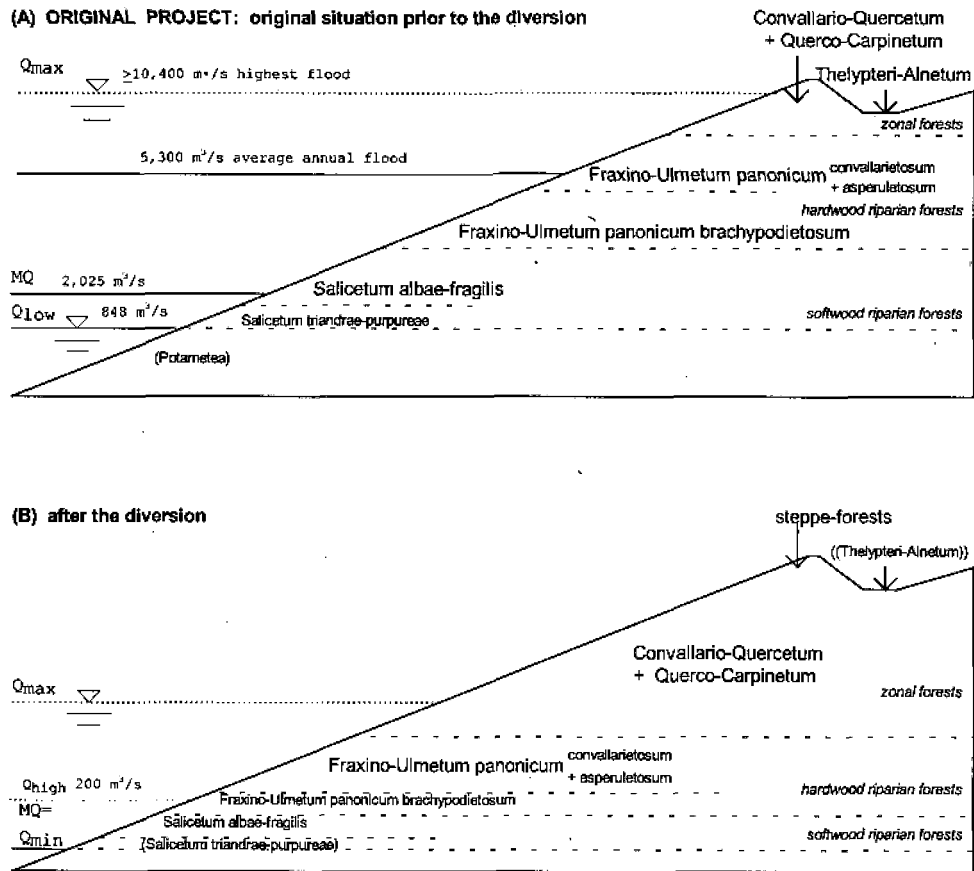
Figure 4.5: *Impacts of the Original Project on the natural vegetation of the Szigetköz.*

The schematic cross-section without scale shows the (simplified) natural potential vegetation (cf. Kárpáti and Kárpáti, 1991) and the predictable reduction of its areas (highest flood 1954 at Bratislava; MQ: average flows; Q_{low}: average low flow; Q_{high}: allowed occasional high discharge = 200 m^3/s; Q_{min}: lowest flow = 50 m^3/s). The shrubby association of Almond-leaved and Purple Willow (Salicetum triandrae-purpureae) on the banks will decrease drastically due to the reduced morphological dynamics in the main channel. All the other associations will shrink to much smaller areas and lower levels due to the reduced inundation. The species composition of all, even of the oak forests (Convallario-Quercetum) and the oak-hornbeam forests (Querco-Carpinetum) in its lower levels, will modify. However, the latter will not achieve full diversity because the sparse floods will prevent the establishment of their zonal elements, i.e. species which do not endure inundation at all.

Older forests on small topsoil layers or with previous seasonal groundwater supply would recede, younger ones would reduce their leaf area if the abiotic conditions were not too extreme (cf. Hary and Nachtnebel, 1989). Rejuvenation would stop just as dynamics do. Instead, as a sign of degradation, other communities would

spread out in periodically or permanently wet depressions such as swamp forests of the *Thelypteri-Alnetum* (with black alder) which are typical for areas far away from the main channel at the edge of the floodplain. However, most of their former stands would die. The aquatic macrophytes (class of *Potametea*) would suffer from the vanishing surface waters in the side branches being scarcely scattered in the main channel anyway.

In addition, large parts of the floodplain would lose its occasional contact with groundwater since the maximum level of floods will decrease considerably (see *Chapter 3*).

Another indicator emphasises the degradation. The grey alder (*Alnus incana*) is a typical tree of subalpine rivers preferring initial stages and raw soils, mostly on gravel banks. These pioneer phases had become rare because of the reduced morpho-dynamics and so did *Alnus incana* (Simon et al., 1993). Almost the same happened at the Upper Rhine about 100 years earlier when Tulla's rectification works forced the river to flow in a new straightened bed. The 3,448 islands and the numerous branches of the braided zone between Basel and Strasbourg vanished and the new channel degraded by up to 4 metres until 1900 (cf. Lösing, 1994). Today only a few patches with some specimen of *Alnus incana* are still present in the floodplains of the Upper Rhine. They have been decreasing continuously since the last century. This example shows how slowly the change, especially in the composition of tree species, actually takes place.

However, 64% of the vegetation in the active floodplain of the Szigetköz indicated a near-natural status (Simon, 1992) before the real implementation of Variant C and the resulting desiccation of the upper and middle Szigetköz. Regarding the whole Szigetköz area of approximately 37,500 hectares, about 25% was covered by near-natural or semi-cultivated plant associations such as forests, poplar and willow woods, aquatic vegetation, marshes and pastures. Although they were planted on most of the sites, the poplar and willow stands are regarded as near-natural associations because they accommodate floodplain elements and even some montane elements (Mészáros et al., 1993).

The anticipated impacts of the Original Project influencing the ecosystem of the Szigetköz can be summarised as follows (cf. Mészáros et al., 1994a):

- a drastic reduction of the discharge in the main channel of the Old Danube;

- significant changes in the groundwater levels (primarily its decline);

- floods fail to enter the floodplain except at a discharge $\geq 6,500-7,500$ m^3/s (the Old Danube receives additional discharges above 4,000 m^3/s only);

– the floods actually entering the floodplain and the almost desiccated main channel arrive in an extremely short time and with high velocity;

– daily fluctuations of several metres in the water level with inverse flow directions, primarily in the middle and lower reaches, as a result of peak-operation at Gabčíkovo.

4.4.2.4 The Nagymaros Reservoir and its downstream section

With the implementation of the Original Project, approximately 20 islands, peninsulas and large parts of the shoreline would have been submerged. The narrow but active floodplain would have been destroyed completely.

Peak power operation

The shores being the ecotone of the moving littoral (Junk *et al.*, 1989) would have been attacked by daily water level fluctuation of 1-4 m, depending on the location in the reservoir. Additional rip-rap would also have hindered the settlement of vascular plants. In a word both strips of daily inundation would have been free of vegetation – a devastated belt.

Such bare bands are well-known from the shores of pumped storage lakes, high dams and upland reservoirs although they are usually induced not by daily but by periodical alternations. Peak-power operation at the Greek river, Arachthos, near Arta, resulted in severe damage of the banks and the devastation of the formerly braided, nearly unregulated river bed.

General impacts of peak power operation on aquatic habitats

Peaking flow operation is the most harmful mode of operation for two main reasons: the initial surge of water released into the tailwater during start up of the turbines, and the highly fluctuating water levels in the tailwater. The surge period is a highly turbulent one. Very rapid changes occur in depth and velocity. The surge scours the rare macrophytes, the periphyton, the invertebrates, juvenile fish, and it disorients adult fish. The sudden changes in flow can exceed the rate of reaction of animals and some are stranded at low flows. Others are entrained by high flows. Highly fluctuating water levels include "fluctuating zones" in the tailwater unsuitable either for terrestrial or (especially) aquatic organisms. Terrestrial or aquatic macrophytes simply cannot develop. Very few specialised benthic invertebrates are able to survive in these zones, particularly *Oligochaetes* and *Chironomids*. Spawning sites and nursery zones for fish cannot exist; embryos and juveniles of fishes cannot survive. Even if they are drifting from side-arms or other tributaries, they will be washed out by the next surge or they will die from desiccation or rapid changes in temperature.

Peaking hydropower also modifies drastically the substrate of the channel; near the dam, erosion increases and further downstream sedimentation rates increase (see *Chapter 2.3.2*). Consequently those processes affect the aquatic habitats and the organisms not only in the immediate zone downstream of the dam but much farther by deposition.

4.5 IMPACTS OF VARIANT C

by Joachim Lösing and Albert Roux

In general, the ecological effects of Variant C are expected to be similar to those outlined above for the Original Project. Thus, this section will focus on differences in impact and observed effects while considering the implications of Variant C structures and operation.

4.5.1 ČUNOVO RESERVOIR

Approximately 4,500 ha of alluvial forests are seized. The predicted forecasts of what will occur have been discussed in the previous sections and in Chapters 2 and 3.

4.5.2 THE SZIGETKÖZ

Shortly after the diversion, the main channel and its side branches were left practically without water. The water level decreased by 3.0 metres at rkm 1850 and by 2.4 metres at rkm 1825 in less than 4 days. The width of the Old Danube narrowed by 55 metres on average. This abrupt change had a severe impact on living communities in this region, especially on fish and other aquatic biota as well as softwood trees.

Aquatic habitats

The diversion of Danube water into the power canal induced not only a lowering of the water level in the main channel but affected all the waterbodies of the floodplain (*Plate 4.2, Volume 5*). Comparing the present situation with pre-dam conditions, the loss of habitat diversity and consequently the loss of biodiversity appears clearly. The most harmful effect is the complete drying of some paleopotamic milieux like the Lipót area. The disappearance of most of the parapotamic waterbodies is to be emphasised. Indeed, these arms which are permanently connected with the main channel and fed by both surface and groundwater present the most important diversity of aquatic habitats and consequently the highest biodiversity. It is not surprising that these parapotamic

waterbodies containing the most valuable fish are the most dangerously damaged (*Plate 4.3, Volume 5*).

The termination of contact between the branch system and the Old Danube caused severe damage to the benthos, the plankton and the fish fauna. A number of detailed studies has been produced on fish kills occurring as an immediate impact (see in Mészáros *et al.*, 1993, 1994a, 1994b, *Chapter 5.4*).

In the branch system of the Upper Szigetköz, the water level was critically low in the spring and early summer up until the beginning of the temporary water supply by pumping in July 1994. The formerly large and uninterrupted reaches were separated into several tiny waterbodies. Inevitably, the number of individuals within the rheophilous[5] species decreased to a greater extent than those favouring stagnant waters. Several rheophilous migratory species reappeared due to the temporary water supply. However, the numbers within non-migratory rheophilous species declined compared to the previous stage. In short, the order and balance among communities was upset by the drastic changes in the biotopes of the active floodplain.

Middle section of the Szigetköz

In the middle reach of the previous main channel, from the end of the Hungarian branch system at Ásvány to the conjunction with the tail-race canal, the surface waters have backed up to rkm 1820-1825, i.e., 9 to 14 kilometres up to the area of Lipót. This section has lost its sub-montane stream character as well. Not only the total number of fish but also the number of fish species has decreased in this stretch. The main channel has lost its function and the rheophilous species are present in small numbers, if at all. Therefore, the most significant immediate change has taken place in this reach from the fish-faunistic aspect. Another chain of barriers would have been built by the "underwater weirs" in the main channel transforming the ecological conditions from those typical for running waters to almost lacustrine conditions in the several impoundments of the small barrages (see *Chapters 2.5* and *4.6*).

The old floodplain (protected side of the floodplain)

As a result of the artificial water supply, the marshy oxbow lake of the Zátony Danube, originally stagnant, became a canal with a flow velocity at some places of 0.4-0.8 m/s. As a result of the provision of supplementary water from the Moson Danube, the fish fauna of the latter was introduced to the Zátony Danube. For this reason, the number of fish species increased significantly, but only one species of

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[5] (attribute of species which prefer running waters with distinct velocity)

the previous fish fauna survived in large numbers (*Cobitidae*). The increase in number of fish species must not divert attention from the fact that the original fish fauna has lost importance. The number of individuals within these eurytropic[6] species became high and their excessive proliferation may lead to the decline of the former (mostly stenotropic[7]) biota *en masse* (Mészáros *et al.*, 1994a).

Among the oxbow lakes in the old floodplain, the mortlake at Lipót was outstanding in terms of its faunistic value. It dried out completely as a result of the diversion and its fish fauna was destroyed. The provision of supplementary water from the main channel could not restore previous fish fauna. During repeated investigations, none of the species of the original fish fauna could be found.

As another result of the diversion, the water level in the canals fell significantly. The flow slowed down or even stopped. Consequently, the situation for the rheophilous species became critical. The impact of the intervention appeared with some delay due to the now exclusive contact through the groundwater (Mészáros *et al.*, 1994a).

Floodplain vegetation

Water-weed communities grew mainly in the oxbow lakes, ponds and canals in the Szigetköz, and as such, they came to the verge of extinction in the upper and middle parts of the Szigetköz. In terms of their prospects for survival, it depends primarily on the efficiency of the provision of supplementary water.

The marsh communities are somewhat more tolerant than the water-weed communities. Their more extensive populations lived only in the active floodplains of the Szigetköz. Nonetheless, the decline in the water-tables seriously threatens these populations·in the upper·and middle Szigetköz.

The willow forests of "the Szigetköz region [were] fairly close to the natural conditions, especially in the Moson-Danube branch, because of the huge meanders" (Simon *et al.*, 1993, p. 179). This desirable situation has been improved slightly by. Variant C in the protected side of the Szigetköz. However, natural floods, as they are characteristic for active floodplains, did not return. Moreover, the situation of the active floodplain of the Szigetköz has been worsened (see *Plate 12, Volume 1*). After June 1993, partial water deficiency could be seen in the forests. Yellow patches occurred on the leaves and branches begin to shrivel. From June onwards, trees started to lose their leaves. By mid-June, 3% of the alluvial forests were classified as dead. At the end of 1993, 5% of the trees were classified

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6   (attribute of species which are able to adjust to large fluctutions in environmental factors)

7   (attribute of species which are inable to tolerate more than slight alternations in ecological conditions)

as dead. The monitoring shows that reduction of the leaf area did not come to an end in 1994 (Simon, personal communication, publication in prep.).

Summarising, the effects of Variant C on the floodplain vegetation do not differ seriously from those predicted for the Original Project (see *Figure 4.5*). The actual increase of the everyday water levels is insufficient for the further existence of the floodplain habitats.

4.6 EVALUATION OF REMEDIAL MEASURES
by Joachim Lösing and Albert Roux

Although there was no agreement in the Original Project to build "underwater weirs" in the old riverbed, they were considered in order to maintain the water at a constant level corresponding to the low flow water in pre-dam conditions. In the same manner, the construction of various weirs in the Danube floodplain (side-arm system) was proposed to maintain the height of the local water-table and to obtain a constant flow (SM, para 2.70). This proposal of *constant* water level, of *constant* flow to be maintained or created, is the sign of neglect of the ecological functioning of a river and its floodplain.

The biodiversity of the floodplain hydro-system is dependent on the diversity of habitats (mosaic of structures). This diversity derives from the variability both in space and time of the different factors of the biota. The most important factor controlling the floodplain ecosystems is the variation of the water levels (including inundations) induced by fluctuations of the discharge. "The principal driving force responsible for the existence, productivity, and interactions of the major biota in river-floodplain systems is the flood-pulse [...]. The pulse is coupled with a dynamic edge effect, which extends a 'moving littoral' throughout the aquatic/terrestrial transition zone (ATTZ). The moving littoral prevents prolonged stagnation and allows rapid recycling of organic matter and nutrients, thereby resulting in high productivity. Primary production associated with ATTZ is much higher than that of permanent waterbodies in unmodified systems" (Junk *et al.*, 1989).

It is evident that all these benefits will be lost when weirs are built either in the Old Danube or in the recent floodplain.

4.6.1 "UNDERWATER WEIRS"

The "underwater weirs", which should correctly be called "weirs", would not have the desired effects on the surface- and groundwater levels as pointed out in *Chapter 2.5*. For the ecological impacts on flora and fauna the following findings from *Chapter 2.5* are of primary importance:

– The weirs would dissect the Old Danube into a sequence of small reservoirs, even at higher discharges;

– The groundwater-table would be controlled by the low surface water levels of the upper end of the impoundments;

– The flow velocities would be reduced to about one third of unbacked flow conditions, thus leading to at least temporary siltation;

– The variability of the flow velocity would be considerably reduced;

– The 'construction of the weirs would lead to rather uniform flow conditions with the consequence of rather uniform riverbed habitats.

After the construction of "underwater weirs" the survival of aquatic species in the Old Danube would be restricted to a few species adapted to almost stagnant waterbodies and able to resist rapid rise of discharges.

The diversity of aquatic species would be reduced by the physical and chemical parameters directing to eutrophic conditions above silty deposits instead of gravel. Subsequently the benthos coenoses would change considerably. The rare events of flood discharges would wash out the biota just gaining a foothold. Aquatic macrophytes would not be able to settle in this short-term environment although the prevailing conditions would fit very well. Thus the entire habitat would be unsuitable for spawning and juvenile fish. In a few words, the riverbed of the Old Danube would lose almost all its entire biological value.

The Upper Rhine experience shows that the groundwater-table as one of the vital elements in a floodplain ecosystem could not be sustained to its previous levels, not even at a constant level. So, also the adjacent floodplain itself would profit less than expected.

With weirs representing a sequence of small barrages in a small river, the last remaining river continuum in the stretch of the Original Project would be segregated again, transforming the environmental conditions from those typical for running waters of a large river to almost lacustrine conditions with flow velocities of 0.1 m³/s to 0.6 (-0.7) m³/s at Q=350 m³/s (see *Chapter 2.5*).

Even though rare flood events may mitigate the effect of segregation, the risks are rising that the small populations in the impoundments will shrink or become extinct due to predators, pests, eutrophication or other inter- and intra-specific effects. Those small rearrangements may even result in total extinction, as can be observed everywhere in the world in recent decades. At least they drastically reduce the genetic pool (bottle neck effect, see *Chapter 4.1*).

4.6.2 ARTIFICIAL WATER INPUT IN THE SIDE-ARM SYSTEM

The decline of the Danubian inland delta in recent decades was a result of excessive gravel exploitation beginning in the 1960s (see *Chapter 2.2*). Subsequently several side-arms (or parts of them) dried out at times or lost contact with the main channel. The equilibrium of the ecological conditions, achieved in the 1950s and 1960s, was disturbed again (especially since the beginning of the preparations of the Gabčíkovo-Nagymaros Project). But the real incision was made with the implementation of Variant C when the whole stretch of the Szigetköz, including the Slovak side, fell dry at once.

The Slovak watering system (starting in May 1993) was planned to mitigate or even improve the ecological conditions. The Slovak Memorial itself names the technical side of the structures:

> "The Dobrohost intake supplies a regular flow of around 50 m^3/s into the side-arm, which is planned to increase to 140 m^3/s 1-3 times per year to achieve the inundation of the side-arms as would occasionally occur under natural conditions. The maximum flow through this intake is 234 m^3/s...[The] left side-arm system has been divided into 8 distinct zones, each with its own water level. These zones are graded as to form a cascade from Dobrohost to Gabčíkovo..." (SM, para 5.42).

It is remarkable that a regular flow of 50 m^3/s as the only intake should be enough to supply an area of approximately 4,000 hectares and that 234 m^3/s should simulate floods of up to 4,000 m^3/s (distributing over both sides of the recent floodplain).

The WWF statement (Dister *et al.*, 1994) goes on to say:

> "Even though in 1991 the Slovak Environment Ministry expressively (!) criticises such measures as very detrimental and demanding a solution ensuring a water input in the side-arms from the [Old] Danube and a removal of the closures between the river and the side-arms [...], the Gabčíkovo engineers started to build this scheme in winter 1992/93 destroying parts of the side-arm system, reinforcing the closures with the Danube and starting a permanent inundation of the wetlands in May 1993. [...These] dykes will transform the previous continuum of the floodplain into a chain of practically independent ponds which *perhaps give the impression of an intact wetland at first sight and in very short term.* It may even be true that the new water levels [...] lifted the water level to a higher level than under pre-dam conditions. However, the single-point inflow of water, its stable, significantly reduced volume and its changed water quality [...] in fact result in detrimental effects.

> The water level just upstream from each lateral dyke is lifted too high and remains stable over many months. This is damaging for natural floodplain

biocenoses. [...] *This measure induces a real threat to the affected floodplain forests.*"

Willow trees are having clear physiological problems since their bases are permanently flooded. Large numbers, especially of large old trees, will die or have died already. The lateral dykes (or dams) proved to impede the migration of fish and other aquatic biota, so that the fish biomass dropped drastically. Almost all large fish vanished and only a few species dominate (for instance bleak [*Alburnus a.*]). The originally rich biodiversity is largely changed today (Roux, 1994).

Biological investigations at the upper Rhine have also proven the effects of such artificial side-arm systems. Krause and Hügin (1987) emphasise as a result of their analysis that "the planning of management systems of connected side-arms cannot be accepted any more."

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CHAPTER 5

SOILS, AGRICULTURE, FORESTRY, FISHERY

5.1 SOILS

by Howard Wheater
(based on Várallyay, 1993)

5.1.1 INTRODUCTION

The area affected by the Gabčíkovo-Nagymaros Project is, as noted in *Chapter 4*, a large alluvial plain, rich in various valuable natural ecosystems, with high diversity and fine landscapes. At the same time, the area is a traditionally important agricultural region of Hungary, and hence there is abundant information on, and a good understanding of, the soils and associated environmental factors, supported by extensive long-term observations, field experiments, and experience of agricultural production (*Table 5.1;* MTA, 1994 and Várallyay, 1991).

The area has a continental climate, with considerable temperature extremes (cold winter, hot summer) and low precipitation. The soils of the Danube alluvial terrace with favourable hydrophysical characteristics and moisture regimes effectively moderate the weather extremes over much of the region. High quality groundwater is drawn up by capillary action to provide an important contribution to the water-use of natural vegetation and cultivated crops. However, this can only occur where the groundwater-table reaches the fine-grained sediment (sand/loam/silt) which overlie the gravel aquifers of the alluvial terrace (see *Plate 3.4*). A high geothermal gradient exists throughout the region, and the availability of good-quality hot waters at moderate depths provides particularly favourable conditions for intensive vegetable production.

The characteristic geological structure of the alluvial terrace has developed in response to the geomorphological effects discussed in *Chapter 2*. The area has high horizontal heterogeneity and vertical stratification, and variable depths of fine sediment. Hence the natural and agricultural ecosystems of the region show high spatial and temporal variability, and, as noted above, are in particular sensitive to capillary moisture supply to the root zone from the underlying groundwater. This moisture supply is primarily dependent on:

    1) the profile of the soil above the gravel strata and its associated hydrophysical properties;

    2) the depth and fluctuation of the groundwater-table.

Table 5.1: *Soil mapping activities in the Bős-Nagymaros Project Area*

	Mapping project	Scale	Date	Cartographic basis	Content
1.	OTTK	1:10 000	1957-1959	Gauss-Krüger map sheets	Soil type, subtype, local variety: colour; most important soil properties (texture, pH, carbonate status, depth): signs.
2.	Géczy practical soil maps	1:25 000	1958-1961	settlements	soil type, subtype, local variety: colour; colour diagrams of representative soil profiles; characteristic land use and cropping pattern
3.	Genetic soil maps	1:10 000	1960-1970	farming units (state and cooperative)	soil map; cartograms/thematic maps/ on the most important soil properties and on recommendations for rational land use, cropping pattern and agrotechnics; data of field survey and lab analysis; explanatory text
4.	Soil map of Győr-Sopron County	1:75 000	1959-1960	Győr-Sopron County	soil type, subtype: colour; most important soil properties (texture, pH, carbonate content, depth): signs.
5.	Program of the "Assessment of the agro-ecological potential"	1:100 000	1978-1980	TIEDIT map sheets	soil map indicating 7 characteristics (soil classification unit; parent material; soil reaction and carbonate status; soil texture; hydrophysical properties; organic matter resource; depth of the soil) with an 8-digit code system; explanatory booklet — with territorial data)
6.	Agrotopographical map	1:100 000	1988-1990	EOTR topographical map sheets	9 soil characteristics (the above-mentioned 7+clay mineral associations; and soil productivity index) with a 10-digit code-system; most important meteorological characteristics on small-size maps and diagrams
7.	Soil of Mosonma-gyaróvár and its surroundings	1:25 000	1983	Mosonmagyaróvár and its environment	5 most important soil characteristics (soil type, subtype; carbonate-content; texture; depth of the humus horizon; depth of the soil) with a 5-digit code-system; explanatory text
8.	Geological Atlas of Kisalföld	1:100 000	1990-1993	Győr-N., Győr-S., Mosonmagyaróvár, Kapuvár atlases	genetic soil map; map of the limiting factors of soil fertility; small-size thematic maps (pH, $CaCO_3$-content, groundwater conditions); explanatory text

These two sets of factors are not independent. As will be discussed below, the soil physical and chemical properties reflect the origin of the alluvial parent material and the water regime.

Depending on the territorial variability of the above factors, the soils, natural vegetation and biomass productivity of agricultural land vary considerably. A wide spectrum of landscapes results, including periodically inundated floodplains, with fresh sediment supply, and highly productive agricultural areas, dependent on the natural sub-irrigation of the underlying groundwater. This is an environment in a dynamic equilibrium. Any human intervention on a large scale will change this state, possibly irreversibly. It is evident that the complex interrelation of physical, chemical and biological processes must be fully considered before such changes occur.

In this chapter, soil formation processes are described, and existing soils in the area of the old floodplain (flood-protected area) are briefly characterised (see *Plate 5.1, Volume 5*), with particular regard to the soil moisture, soil chemical and plant nutrient regimes. Potential long-term impacts of the proposed GNB Project on soils and soil water are discussed.

5.1.2 SOIL FORMATION PROCESSES

In the alluvial terrace of the Danube, the main parent materials for soil formation are fluvial alluvial deposits. In the higher ground of the Moson Plateau (Mosoni Síkság), to the south-west of the Mosoni Danube, soil development began on loess material, mixed with various alluvial deposits and re-deposited repeatedly by fluvial action; and in the transitional region beyond, towards the Fertő and Hanság depression, it was based on lacustrine sediment (peats) (MTA, 1994 and Várallyay, 1991).

The alluvium is characterised by high carbonate content (reflecting the limestone origin of the Danube sediment) and has a high degree of vertical stratification (layering) and horizontal variability in soil texture. On this "raw" parent material two primary soil processes began: humus formation and soil structure development. Depending on the history of fluvial deposition, and the development of the humus horizon and other features of the soil structure, a time sequence of soils can be clearly distinguished in the alluvial terrace region (Stefanovits, 1992.):

alluvium→ alluvial soils→ humous alluvial soils (The latter refer to alluvial soils with a humus horizon)

The rate of soil development (soil formation) depends on the moisture conditions; on the particle-size distribution, carbonate content and original organic matter content of the alluvium; on the character of natural vegetation; and on land use and/or agricultural development. It occurs on a time-scale of hundreds of years.

The further development of the humous alluvial soils is primarily determined by the moisture regime, which in turn is dependent on rainfall, groundwater conditions and soil hydrophysical properties. As rainfall is relatively uniform over the region, groundwater conditions have been a dominant influence in determining the spatial distribution of soils. As the depth to the groundwater-table is closely related to relief, a general topographic sequence (catena) of soils can be observed:

chernozem→ meadow chernozem→ meadow soils→ peaty meadow soils→ peat (bog)

In this sequence, the influence of groundwater is minimal for chernozem soils, but is progressively more important moving through the sequence. Thus in the case of peat soils, the impact of periodic or permanent water-logging is the dominant factor of soil formation.

The influence of groundwater depends on the location of the water-table in the vertical profile. If the groundwater remains wholly within the gravel strata, capillary rise is prevented, and its effect on soil processes is negligible. In such cases the sequence can be reversed, for example with humous alluvial soils developing in the direction of "terrace chernozems".

On the extensive alluvial terrace of the Danube and the Mosoni Danube, in the Szigetköz region and its surroundings, the three cases described above can all be found, i.e.:

1) alluvium – alluvial soils – humous alluvial soils

2) humous alluvial soils (topographic and hydromorphic sequence) mostly meadow soils and meadow chernozems

3) humous alluvial soil – terrace chernozems

The consequence is the mosaic-like spatial variability of slightly alkaline soils (pH 7.3-8.3), with heterogeneity in stratification, $CaCO_3$-content, depth of humous horizon and its organic matter content, texture, hydrophysical properties, depth of gravel strata and groundwater conditions.

On the Moson Plateau, soil development began on loess or loess-like deposits, without any groundwater influence, hence tending to chernozem soils. The other soil types of the hydromorphic sequence (meadow chernozems – chernozem meadow soils – meadow soils) occur only in the deeper parts and microdepressions of this area.

In the transitional areas towards the Lake Fertő and Hanság depression, the wetter members of the toposequence predominate, i.e.:

meadow soils →peaty meadow soils →peat soils.

5.1.3 SOIL TYPES

The most important characteristics of the main soil types of the region (see *Plate 5.1, Volume 5*) are summarised below (MÁFI, 1989, 1991a, 1991b, 1993 and Várallyay, 1983):

Weakly developed humous sandy soils

Occurrence is limited. Main characteristics are a weakly developed humus horizon, low organic matter content, low water storage capacity and retention properties, no capillary water supply, high drought-sensitivity.

Alluvial soils

The various alluvial soils in the region, developed from different Danube deposits, are light textured (mostly sand, sandy loam, sandy silt, partly silt, loam, silty loam), are slightly alkaline (pH 7.3-8.3), and are calcareous in the upper profile ($CaCO_3$ content 10-25%) in most cases.

The vertical profile of alluvial soils shows the typical alluvial deposition sequence of various particle-size fractions: silt – sandy silt – silty sand – fine sand – coarse sand – fine gravel-gravel, with the texture becoming coarser with depth. The gravel strata occur within the upper 1.5 m of the soil profile in many cases. The moisture regime of alluvial soils depends primarily on three factors:

1) the water retention characteristics of the topsoil;

2) the depth of the gravel strata;

3) the presence of a groundwater-table within the fine sediment of the profile.

The capillary moisture supply can be as high as 150 mm/year under favourable circumstances, for example a sandy silt/loam/loamy silt texture and water-table at 1.5-2 m depth, located within the finer sediment. However, if the water-table only occurs in the underlying gravel, the capillary transport becomes negligible, which results in drought sensitivity, particularly for shallow soils.

Alluvial meadow soils

The alluvial meadow soils of the region are characterised by slightly alkaline reaction (pH 7.3-8.3) and highly variable $CaCO_3$ content (0-25%). In comparison with the alluvial soils, their texture is relatively heavier (loam, clay loam, clay), and their humus horizon deeper (>40 cm), with 2.5-4.0% organic matter content. The well developed soil profile is evidence of the long-term soil formation

processes on the Danube and Lajta alluvia. The groundwater influence on the soil formation processes is clearly reflected by the hydromorphic features within the soil profile (especially in the deeper horizons): for example, iron mottling, and the development of carbonate accumulation or even petrocalcic horizons. The capillary moisture supply from the groundwater is highly significant in these soils (except for shallow soils with gravel occurrence near the surface. It can reach 200 mm/year from a 1.5m deep groundwater-table (Várallyay, 1974a and Várallyay and Rajkai, 1989).

Chernozems formed on loess or on loess-like materials

The chernozems of the Moson Plateau are medium-textured (loam, sandy loam, silty loam), with slightly alkaline reaction (pH 7.3-7.9), a favourable carbonate status ($CaCO_3$ content 1-15%), and 2-3% organic matter content. The depth of their humus horizon greatly varies (20-70 cm), mostly due to the influence of lateral soil erosion. They have favourable hydrophysical properties. Their capillary moisture supply from deep groundwater generally is not significant, but, because of the favourable capillary conductivity of the subsoil and the loess parent material, cannot be neglected, particularly in dry years.

Terrace chernozems on alluvial material

These soils can be characterised by slightly alkaline reaction (pH 7.5-8.1), medium organic matter content (2.0-2.8%), variable 1-25% carbonate content ($CaCO_3$), . medium texture (loam, sandy loam), good structure and favourable hydrophysical properties. The groundwater is located in the gravel strata underlying these soils, consequently the influence of groundwater on the soil processes and the capillary moisture supply from the groundwater to the root zone are negligible, even in the case of a shallow groundwater-table. Their shallow varieties (with the near-surface occurrence of the gravel strata) are particularly drought-sensitive.

Meadow chernozems

These soils have limited occurrence within the project area. The periodical wetting of the deeper horizons from a moderately deep groundwater-table permanently located in or, at least, temporarily rising into fine-textured sediment, results in the moderate development of hydromorphic features within the profiles of these soils, especially in their deeper horizons: $CaCO_3$-accumulation horizons, iron mottlings, lime concretions, etc. The capillary moisture transport from the groundwater to the overlying horizons may reach 50-150 mm/year (Várallyay and Rajkai, 1989).

Meadow soils

Meadow soils can be found in the low-lying areas, micro- and mezo-depressions of the area and in the transition belts towards the Fertő Lake and Hanság depression. They are under the permanent influence of the shallow groundwater-table. The consequences are hydromorphic features within the whole soil profile, a deep humus horizon (60-80 cm) with relatively high (3-5%) organic matter content, and the formation of lime accumulation horizons ($CaCO_3$-accumulation – petrocalcic horizon – lime-pan) which may reduce the effective soil depth because of their impermeable (non-penetrable) character. The meadow soils of the region are slightly alkaline (pH 7.8-8.3) with high (15-30%) $CaCO_3$-content and medium texture (loam). Because of their occurrence in low-lying areas with shallow groundwater-table conditions (<100-150 cm) they are particularly sensitive to over-moistening and even water-logging.

Peaty meadow soils

These soils occur in the Northern part of the Hanság-Fertő depression. They are highly calcareous in the upper profile ($CaCO_3$ content: 10-25%), have alkaline reaction (pH $\approx$ 8.0), moderately deep humus horizon (30-50 cm) and widely variable organic matter content (5-20%). Because of the influences of permanent groundwater (and periodic surface water inundation), hydromorphic features are well-developed and strongly expressed within the whole profile.

Peat soils

The peat soils which occur in the Northern part of the Hanság-Fertő depression are alkaline (pH $\approx$ 8.0) and highly calcareous in the upper profile ($CaCO_3$ content: 10—15%). Their organic top-horizon (usually with more than 20-30% organic matter content) is moderately deep (60-100 cm), and in many cases mixed with the mineral, highly calcareous subsoil and/or with the peat material (organic matter 10-60%).

In summary, it can be noted that soils are dynamic and that soil structure and physical/chemical properties have developed in response to prevailing moisture conditions. In particular, capillary moisture supply is an important feature in the water balance of the region. Additionally, the high concentration of salts, e.g. $CaCO_3$, can have significant effects on the physical characteristics of the soil profile.

5.1.4 SOIL MOISTURE REGIMES

As has already been noted, the moisture regime of soils in the flood-protected area of the Szigetköz is determined mainly by:

1) the stratification (layering) of the soils profile: the depth, thickness and sequence of the basewater soil horizons;

2) the hydrophysical properties of the layers (in particular the unsaturated hydraulic conductivity);

3) the depth of the gravel strata from the surface;

4) the depth and fluctuation of the water-table.

For the determination of the quantity of water available to the soils from underlying groundwater, a model has been developed at the Research Institute for Soil Science and Agricultural Chemistry (RISSAC) of the Hungarian Academy of Sciences (Várallyay 1974a, 1974b, 1980; Várallyay and Rajkai, 1989 and Rajkai and Várallyay, 1989).

The model is based on data from an extensive analysis of the hydraulic properties of undisturbed soil columns from the study area. Using an analysis of steady-state evaporation from a near-surface water-table, the maximum contribution under bare soil conditions can be defined, from uniform or layered soil profiles. This is a conservative estimate which neglects the effects of rooting depth, but it provides an effective method for estimation of the optimal depth of the water-table for capillary supply, the critical depth of the water-table to present adverse effects from poor quality groundwater, and the estimates of the contribution from capillary rise to the soil water budget previously referred to.

The practical significance of the capillary rise contribution to the water balance has already been noted. Locally, it can account for one third of crop water use or more. Its contribution is of greatest importance in dry years and in the summer growing season, and it can be noted that the seasonal variation in groundwater levels is determined primarily by Danube flows, which provide maximum supply in the Szigetköz during the period of maximum vegetation water demand (Várallyay, 1980).

5.1.5 NUTRIENT REGIMES OF THE SOIL

The moisture regime directly determines the water-supply of plants, but has a major influence on the air- and heat-regimes of the soil and its biological activity. All of these factors play a considerable role in the plant nutrient regime of soils: the spatial and temporal variabilities of plant nutrients; their changes, transport, abiotic and biotic transformation; their solubility, mobility and "availability" (Várallyay, 1990).

Hence, in the project area the depth and fluctuation of the groundwater-table (as the most important factors of the moisture regime in the root zone) have significant influences on the regime of plant nutrients in the soil (Várallyay et al., 1993; Gergelyné-Gál and Németh, 1989 and Németh, 1994).

Table 5.2: Main characteristics and nutrient content of the topsoil of the investigated agricultural fields

Soil characteristics	No. of profile (field)																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
pH (KCl)	7.55	7.55	6.95	5.80	7.21	6.93	7.27	7.24	7.35	7.48	6.50	7.38	7.45	7.25	7.22	7.19	7.46	7.40
SP	51	45	51	42	40	44	57	57	60	49	50	52	47	59	65	53	61	57
Total salt content%	0.00	0.00	0.02	0.00	0.00	0.06	0.02	0.01	0.04	0.00	0.01	0.05	0.00	0.00	0.00	0.02	0.00	0.01
$CaCO_3$ %	24.2	23.0	9.70	0.00	7.50	2.20	2.3	17.3	21.0	19.2	1.2	22.9	25.3	12.0	18.1	18.4	20.2	8.6
Humus %	1.52	1.76	3.05	3.10	2.62	2.97	2.23	2.61	2.35	2.07	3.31	2.82	1.86	4.30	4.74	2.70	2.80	3.93
NO_3+NO_2 ppm	14.2	16.6	35.0	15.1	9.20	3.90	14.5	36.5	36.9	5.20	8.60	12.8	33.9	18.5	25.9	10.6	17.3	7.36
P_2O_5 ppm	116	183	319	148	216	248	200	262	132	173	73	174	220	292	347	252	290	197
K_2O ppm	151	193	208	315	464	282	192	214	131	163	116	252	272	133	166	174	123	154
Mg ppm	153	173	295	360	127	147	334	251	276	193	352	310	156	315	349	315	201	306
Na ppm	4	60	6	21	37	3.5	8	10	65	5	64		52	77	8		13	6
Zn ppm	2.1	2.40	4.80	3.0	4.10	2.40	2.10	1.50	2.90	2.10	7.0	2.10	3.2	1.80	3.9	1.8	2.3	2.0
Cu ppm	5.4	5.4	5.30	7.5	2.4	2.0	44.9	3.20	4.70	2.30	9.0	4.00	3.4	4.80	5.1	4.1	3.3	3.8
Mn ppm	66	74	44.4	16	69	99.4	14.4	22.1	13.1	15.3	100	17	17.8	47.3	22	28	17.2	33
SO_4 ppm	26.0	29.0	22.9	25.0	26.0	4.8	8.0	28.0	13.6	11.1	11.6	33.6	15.9	28.4	9.7	29.3	21.9	8.0
Year	86/87	86/87	1986	86/87	86/87	1986	1989	86/87	1989	86/87	1987	86/87	1989	1989	1989	86/87	1985	1981

Characterisation of profiles: Alluvial soils (1,2,3,7,9,10,14,15,16,17), Humous alluvial soils (13), Alluvial meadow soil (8,11,12), Meadow chernozem (4,5,18), Terrace chernozem (6)

The nutrient regime of the agricultural soils of the Szigetköz region is summarized in *Table 5.2*, based on 18 representative locations. The studies indicate that:

1) the nutrient supply is in general medium/good in N and P, poor in K;

2) the recorded yields are medium, good and very good;

3) high nitrate accumulation was found at 4 locations, associated with high levels of applied fertiliser.

The issue of nitrate in groundwater was discussed further in *Chapter 3.*

5.1.6 GENERAL IMPLICATIONS OF THE ORIGINAL PROJECT

It will be evident that a central issue underlying the impact on soils, ecology and agriculture is the effect of changes to the groundwater regime. It has been demonstrated that soil moisture is strongly influenced by the availability of groundwater through capillary rise, that this determines the water available for plant-transpiration and also aeration and temperature of the soil. Thus the nutrient status of the soil is affected and, in the long term, soil structure. Indeed, it has been shown that the present distribution of soils has developed in response to the moisture regime.

Three situations can be defined concerning groundwater-soil water interactions, as a consequence of the GNBS Original Project:

(1) Case 1 (*Figure 5.1*) The groundwater is and will remain within the gravel strata; its fluctuation is indicated by small arrows. This effect may extent up to about 30% of the impact area. In these areas, there will be no changes to the soil moisture regime as a result of the Original Project. The capillary transport for the groundwater to the soil is practically zero, independent of the depth of water-table in the gravel strata. These shallow soils have low fertility and particularly high drought-sensitivity, and their productivity is highly weather-dependent.

(2) The groundwater is and will remain fluctuating within the finer-textured sediment. (This effect may extent up to about 30% of the impact area.) In these areas

a) lowering of the water-table will be followed by a certain decrease in the capillary transport from the groundwater to the overlying horizons (Case 2 in *Figure 5.1*);

b) a rise of water-table may result in a certain increase in the capillary transport of water (and soluble materials) from the groundwater to the overlying horizons; however waterlogging may occur in certain areas, with a requirement for remedial drainage measures (not demonstrated in *Figure 5.1*);

The average change in the capillary transport is approximately ±50 mm/year.
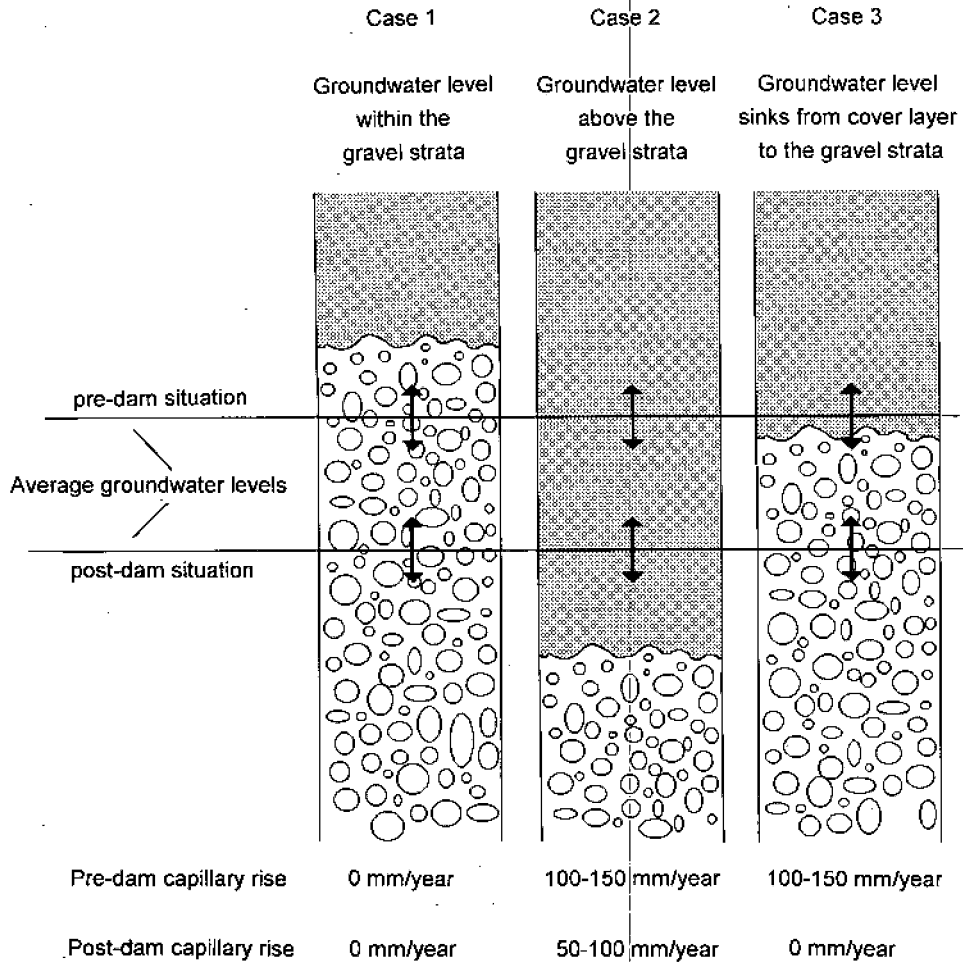
Figure 5.1 The effect of the lowering of the groundwater table on capillary rise

(3) Case 3 (*Figure 5.1*). Groundwater is fluctuating at present within finer-textured sediment, but as a consequence of the changes in the hydrology of the Danube-system (e.g. reduction of groundwater-supply from the original riverbed and from the connecting branches and meanders) the groundwater-table will sink to the gravel strata. This effect may extend up to about 30% of the impact area. In these

areas the capillary water supply from the groundwater will be radically reduced. This capillary transport reduction may reach 100-150 mm/year or more.

Under the given climatic conditions of the area (relatively low atmospheric precipitation and dry vegetation growth period) the relatively favourable (pre-dam) conditions for biomass production (including traditional vegetable production) are based mainly on this capillary water supply from the good-quality groundwater. For agricultural production this ensures high yields and considerably reduces the weather-dependent yield fluctuations (climatic risks). For the natural ecological systems it is essential to their survival. The capillary water-supply is "free of charge", automatic and self-regulating and thus has vital importance in the given region. Consequently, the loss or radical reduction of this moisture supply (50-150 mm/year) can be expected to result in dramatic changes to the soil moisture (and chemical) regimes; in the species spectra and bioproductivity of natural ecosystems; in soil productivity; and in the yields (and yield safety) of cultivated crops.

These consequences for agricultural production cannot in practice be balanced simply with irrigation. Apart from the high cost of irrigation infrastructure, energy and manpower requirements, the potential adverse environmental consequences of irrigation are well known and have occurred extensively world-wide. For the light soils of the region, with poor soil water retention characteristics, frequent irrigation would be necessary, with associated problems of chemical leaching and soil structure degradation, as discussed below. Commonly over-application occurs in practice, with resultant reduction in trafficability and consequent adverse soil structural changes, and also non-uniform irrigation application. In addition, the soils are vulnerable to surface degradation from frequent irrigation application. This is in complete contrast to the naturally occurring processes of subirrigation.

(4) The groundwater remains at present (pre-dam) in the gravel strata, but (as a direct or indirect consequence of hydrological changes in the Danube system) the groundwater-table will rise (at least periodically) to fine-textured sediment. This effect may extend up to about 10% of the impact area. In such cases the moisture-regime consequences are the reverse of the changes mentioned above. In such areas the capillary transport from the groundwater to the overlying horizons may considerably contribute to the moisture supply of the natural vegetation or cultivated crops, a generally beneficial effect.

The estimated territorial distribution of the described cases are in *Chapter 3.4.*

The changes in the moisture regime of soils will be expected to result in important long-term changes to the biogeochemical cycles of various elements, and the chemical regime of the soil. The interrelation between soil water regime and soil structure has been extensively discussed above in the context of soil development. It has been shown that in the long term, soil water regime is a dominant influence on soil structure.

Of particular concern is the effect of carbonate accretion. The high carbonate content of the alluvial soils has been discussed, and reflects their geological origin. The soil structure is sensitive to the development of carbonate accumulation layers, lime concretions and lime coated gravels. These features are commonly observed in their early stages in the region, for example in the Moson Terrace soils (especially in the transition zone with the alluvial terrace and the Hanság Depression) and, of particular interest here, in the soils to the East of Györ. These effects can lead to a hard and impervious petrocalcic horizon or even a solid carbonate hardpan at the boundary of the fine-textured sediment and the gravel strata. (Várallyay, 1983)

The main expected chemical and structural changes are summarized as follows:

1) When groundwater-tables are lowered, the wetting of soils will be reduced, leading to the reduction of their hydromorphic features, and the ratio between the aerobic and anaerobic decomposition of organic material will change. This will lead to increasing mineralisation rates of plant residues as applied organic fertilisers; the consequence will be a loss of soil fertility. Patterns of water and solute transport will change, leading to increased downward fluxes. Downward movement of fine mineral particles from the fine-textured upper horizons can lead to blocking of the large macropores of the gravel strata with, as above, the tendency to develop a cemented gravel layer.

2) Where water-tables rise, increases in soil moisture can be expected. There may be favourable effects of increased sub-irrigation. However, a number of adverse consequences can also be anticipated. These include loss of aeration, leading to unfavourable changes in soil biota, microbiological processes and nutrient regime; problems of tillage and general access by agricultural machines; carbonate accumulation, with implications as described above; secondary salinisation /alkalisation processes under the influences of a stagnant shallow water-table and high groundwater salinity. This last problem is not of major significance for the well drained the Szigetköz area, but is a serious environmental hazard on the Slovak side of the Danube, particularly in the low-lying, poorly-drained areas of the Eastern Žitný Ostrov region.

3) It must also be recognised that changing groundwater flow paths may lead to pollutant transport, and that changes in groundwater quality may adversely affect soil conditions.

5.2 AGRICULTURE

by Howard Wheater
(based on Palkovits, 1994a-d and
Volume 4, Part II, Annex 20)

5.2.1 EXISTING CONDITIONS PRIOR TO THE PROJECT

The Szigetköz is a valuable, fertile agricultural area, with a crop yield 8-12% higher than the regional average. Approximately 30,000 hectares of land are used for agriculture, of which some 22,500 hectares are used for arable production. Historically, the region has been characterised by large agricultural estates, and systematic data collection on agricultural production has been carried out since 1980 for an area of about 20,000 hectares, which includes the production of the 11 most important field crops of the region (some 800-900 fields). Since 1989 major change has taken place to the organisation of agriculture, involving privatisation.

The main factors influencing agricultural productivity are: the precipitation, the groundwater levels and the agricultural management practices

Precipitation

The amount of rainfall and its temporal distribution, especially during the growing season, are key factors influencing soil moisture and, in turn, agricultural productivity.

The annual average precipitation (1951-1990) at Mosonmagyaróvár and Győr was 573 and 548 mm, respectively. However, over the last seven years there has been an 11% reduction in annual rainfall at both sites and a 12-14% reduction in rainfall during the growing season.

Groundwater

There are over 200 observation wells in the Szigetköz. Hence water-table conditions are well defined and the data have been used to quantify average values over the growing season. These indicate that in the period 1980-1992, 53% of the farmland had sufficient groundwater available for natural sub-irrigation due to capillary rise in the soil profile (see *Chapter 5.1*) to meet crop needs.

For 23% of the monitored arable fields, the water-table was within 2 m of the surface, providing a continuous moisture supply. For 30% the groundwater was between 2 and 3 m below the surface, providing either a constant or a temporary water supply. When the water-table occurred between 3 and 5 m below ground

surface, moisture supply was limited, and for depths greater than 5 m, no moisture supply occurred.

Agricultural management practices

These have a number of elements, for example, crop rotation, cultivation, seed-bed preparation, fertiliser application, weeding, pest-control, irrigation, harvesting, etc. The quality of each element has a direct impact on agricultural productivity, which in turn is linked with environmental conditions. Any defect in a given component will put optimum yield at risk. In the later part of the 1980-1992 period, standard management practice met the basic requirements. However, from 1992 technical problems began to emerge. For example, inadequate application of fertiliser had some effects on average recorded yield.

Data analysis

A multi-factor impact analysis was carried out to understand the effects of the key factors on productivity for the 1980-1992 period. All crop species and soil-types were analysed with respect to water-table conditions and yields for dry, average, and wet years. Management practices, especially fertiliser application, were also included. Crops of less than 1,000 ha/year were excluded as providing an insufficient statistical base.

The conclusions were that for all crop species and soil types, yields were linked to water-table levels. Climatic dependence was illustrated by a 9% yield increase in wet years and 9.5% yield loss in dry years, in comparison with average conditions.

For average rainfall years, areas with water-tables within 2 m of the surface showed a yield increase of 10.8%, and for water-tables between 2 m and 3 m below surface the yield increase was 7.4%. The corresponding figures for dry years were more dramatic, namely a 15-19% yield increase for high water-table conditions and 10-11% increase for 2-3 m water-table depths.

5.2.2 IMPACTS OF THE ORIGINAL PROJECT

130 hectares of fields and 260 hectares of grasslands were lost to agricultural production due to construction activities. The effects of groundwater level on crop yields have been discussed, and in *Chapter 3* the areas affected by groundwater level reduction were estimated. Preliminary estimates of associated costs (Palkovits, 1994) were 90-100 million HUF per year due to yield loss. Irrigation costs to replace groundwater supply were similarly estimated to be 66 million HUF on the basis of 1994 prices.

5.2.3 IMPACTS OF VARIANT C

Yield reduction

Following the diversion of the Danube, large-scale decreases in groundwater levels in the Szigetköz were observed. Those have been discussed in *Chapter 3*, and illustrated in *Plates 3.13* and *3.14 (Volume 5)*. Considering the area of the Middle Szigetköz for which agricultural survey data are available, 4,200 ha of arable land lost its groundwater moisture supply. Further areas of the Upper and Middle Szigetköz were similarly affected.

Impacts on agriculture are complex, as changes in the other factors affecting productivity also occurred. 1993 was the driest and hottest year of the period investigated (from 1980 onwards). In the growing seasons, observed rainfall in the Mosonmagyaróvár-Györ area was 87-118 mm (a 40-year low). Precipitation in the first half of the year was unusually low, and this had a large influence on summer-harvest crops. The situation improved for autumn-harvest crops due to heavy rainfall in late July and rainfall in September and October.

Under these dry conditions, the effects of groundwater were particularly important. However, due to structural changes in the agricultural sector and other factors, fertiliser application was reduced, to only 24.8% of the 1989 value, 23% of wheat growing areas had late sowing, there was some deterioration in the quality of seed, and a reduction in field preparation. It is evident that a simple interpretation of observed data is not possible.

The observed data for yield in 1993 in comparison with 1980-1992 are given in *Table 5.3*. The weighted average yield of the 11 main crops was reduced by 20.5%. Using the multi-factor analysis, it is estimated that 22.2% of this reduction is due to reduced groundwater levels as a result of the diversion of the Danube. This table also shows the estimated proportion of crop financial losses due to Variant C, amounting to 49.7 million HUF.

Irrigation

Data from 1990 (a relatively dry year) indicate that a total area of 1153 ha of the Middle Szigetköz received irrigation (average application: 106 mm), predominantly (62%) for sugar beet and mainly from groundwater sources. In 1994 significant changes have occurred. 18% of wells are unusable, and 50% of wells are operating at half-capacity. 42 out of 44 dug-wells now provide negligible water yield. Small canals and open drains have either dried up or have minimal water. It is estimated that irrigation supply has been reduced by 40% and costs increased by 60-80%.

Table 5.3: Yield loss and the influential conditioning factors in 1993 compared to the average values of the period between 1980-1992 (cf.
Volume 4, Part II, Annex 20)

Species	Yield loss		Total		Weather conditions		Groundwater		Techn. faults	
	tons/ha	%	tons	1,000 HUF	tons	1,000 HUF	tons	1,000 HUF	tons	1,000 HUF
Wheat	1.52	-27.6	9,287	78,940	4,756	40,426	2,449	20,816	2,082	17,968
Winter barley	1.63	-33.7	916	7,328	733	5,864	-----	------	1,83	1,464
Spring barley	1.81	-35.8	3,207	25,656	2,001	16,008	683	5,464	523	4,184
Pea(sowing)	1.07	-38.8	1,582	23,730	1,072	16,080	194	2,910	316	4,740
Pea	1.69	-48.4	187	5,610	152	4,560	-----	-----	35	1,050
Sunflower	----	+31.3	----	-----	-----	-----	-----	-----	----	----
Potatoes	4.31	-15.8	879	10,548	578	6,936	125	1,500	176	2,112
Corn	1.51	-22.4	5,483	54,830	3,136	31,360	1,020	10,200	1,327	13,270
Sileage corn	0	0	1,217	1,825	395	592	505	757	317	476
Sugar beet	2.86	-7.0	4,959	12,397	2,370	5,925	1,760	4,400	829	2,072
Alfalfa	0.92	-11.3	557	2,785	340	1,700	101	505	116	580
Grass	-----	-----	2,346	-----	-----	------	1,064	3,192	-----	-----
Total			30,620	223,649	15,533	129,451	7,901	49,744	5,904	47,916

It is estimated that to restore lost irrigation capacity to a minimum, required level would cost approximately 10,08 million HUF. To establish optimal irrigation capacity on the previously irrigated area could cost some 12 million HUF.

The use of irrigation to compensate for natural groundwater sub-irrigation has many disadvantages, as discussed in *Chapter 5.1*. However, preliminary estimates of associated costs for the Middle Szigetköz are in the range 19-39 million HUF at 1994 prices for new wells and associated equipment, and 22.1-30.6 million HUF annually for additional water costs.

In total, to provide a minimum level of irrigation to mitigate damage would cost 51.2 million HUF; optimal irrigation is estimated to cost 81.6 million HUF.

This is in addition to the 10.08-12.0 million HUF to restore lost irrigation-capacity and excludes the cost of yield reduction defined above as 49.7 million HUF.

5.3 FORESTRY

by László Magas

5.3.1. EXISTING CONDITIONS PRIOR TO THE PROJECT

From the point of view of forestry the impact area of the Barrage System on the Hungarian side mainly includes the Szigetköz and the narrow floodplain of the Danube between Gönyü and Szentendre.

The Szigetköz

The floodplain of the Szigetköz has been influenced to some extent by flood protection but is still in a semi-natural state (see *Chapter 4*). Its functioning is vulnerable to change because of its dependence on the flow regime of the Danube. This was demonstrated by the unfavourable changes and decline of the forest communities accompanying the changes in the ecological conditions of the natural floodplain downstream of Bratislava (Cifra, 1987). The composition and the productivity of the forest communities of the floodplain in the Szigetköz are basically determined, within the framework of river regulations, by the regime of the Danube (Járó, 1977 and Halupa and Járó, 1987). In addition, timber productivity is determined by the genetic characteristics of the trees and climatic and soil conditions as pointed out in *Chapter 5.1* and *5.2*.

The area belongs to the climatic region of Kisalföld. Its macroclimate represents a transitional region with dry, warm and hot summers as well as with moderately dry, moderately warm and mild winters. Within its macroclimate, a specific meso-

climate evolved in the floodplain of the Szigetköz. The numerous branches of the Danube, oxbow lakes, lowland areas without drainage, marshes and reed areas create substantially more humid conditions than the ones characteristic to the macroclimate of the whole Szigetköz.

The water regime combined with the morphology of the floodplain shows its effect on forest communities. This is especially true for the Szigetköz, which, without the Danube, would be a wooded steppe, and look like the Great Hungarian Plain, where forests struggle to survive, and forest cover is substantially lower than elsewhere in the country. In the wooded steppe climate, the precipitation is not sufficient to sustain forests, thus forest communities survive and develop only on such habitats where some type of extra water is available to them in addition to rainfall.

The hydrological conditions of the floodplain depend on the elevation of the area above water level, which affects the water-table levels and for how long the area is inundated. The rising of the groundwater-table caused by Danube floods has at least the same significance as actual surface water inundations. Accordingly, before the diversion of the Danube three main types of forested habitats could be distinguished here (proportions calculated from the database of the Forestry Management Planning Service (1988, 1994)):

1) Areas with medium high elevation, flooded 1-3 times a year for short periods only. 20% of the active floodplain (between dykes) belongs to this type;

2) Areas with medium low elevation, flooded 2-5 times a year, the duration of inundated conditions can make up one sixth of the vegetation period. The forest is continuously supported by groundwater supply. This is 71% of the active floodplain;

3) Areas with low and extremely low elevation, submerged under conditions of higher than 430 cm gauge value at Dunaremete, which is characteristically longer than one sixth of the vegetation period (7%);

4) The remaining area belongs to the high and extremely high habitats (2%).

Soils of the forests in the Szigetköz have developed on the gravel deposited by the river. Accordingly all stages of soil-development can be found in the area from the raw to mature alluvial loam (discussed in *Chapter 5.1*). They are usually calcareous, which negatively affects tree growth only in drought stressed conditions.

Characteristic natural forest communities of the Szigetköz are as follows:

1) Bushy willow stands *(Salicetum purpureae)*
These willow stands developed in the deepest sites, representing the pioneer arboreal stage of forest succession.

2) White willow forest *(Salicetum albae)*

This is the dominant, frequently flooded forest-type of the river-bank.

3) Willow-poplar gallery forest *(Populo-Salicetum)*
This mixed forest occupies slightly more elevated places than the previous white willow stands. It is dominated by the black and the grey poplar, white willow and alder. A very productive forest.

4) Oak-ash-elm forest (*Ulmo-Fraxino-Quercetum roboris*)
It covers the elevated areas of the floodplain which are rarely inundated. It is characterised by high diversity of trees and bushes.

5) Grey poplar forest (*Populetum canescensis*)
This forest grows in elevated places, where soil conditions are unfavourable to hardwood forest.

Section between Gönyü and Szentendre

This section, although fairly long, does not represent as significant economic value as that of the Szigetköz. The narrow gallery forest, however, is a very valuable ecological aesthetic and recreational contribution to the landscape.

5.3.2 HISTORICAL DEVELOPMENT

Natural forest trees of the Szigetköz have been partly replaced by hybrid-poplar varieties in the last 50 years. Particularly the willow-poplar forest communities of the active floodplain were affected. This change, however, has left the understorey and the animal life more or less intact.

At the same time, new plantations were established in places of pastures and meadows which now represent 20-30% of the forest. The total ratio of the hybrid-poplar is 64% in the active floodplain.

Prior to the onset of construction there were forests on 8,600 ha in the Szigetköz. Out of this, 1,000 ha have been cleared. Actually there are forests on 4,443 ha in the active floodplain and 3,161 ha in the flood-protected area (outside of dykes).

The largest proportion of timber production is made up of poplar, ash, willow, and oak. Because of the (formerly) exceptionally favourable habitat conditions this area is recognised as the most productive timber resource of the country. The yearly growth of timber in the active floodplain can reach 25-30 m^3/ha in some islands. The average is 16 m^3/ ha which is more than two times greater than the average of the country (Forestry Management Planning Service, 1994). The yearly timber production was 50-60,000 m^3 before the Project.

5.3.3 IMPACTS OF THE ORIGINAL PROJECT

The average discharge of 2,000 m³/s would have been reduced to 50-200 m³/s in the main channel between Dunakiliti and Ásványráró. It was intended to supply 15-25 m³/s to the Hungarian side branch system (see *Chapter 3.2*). The riparian forest was recommended to be replaced by xerophytic, drought tolerant tree species. These species are unfavourable for valuable timber production and function as "green area" only.

In the section between Gönyü and Szentendre altogether 150 ha of forests were cleared in connection with the construction. Forestry started to suffer very substantial impacts in the active floodplain area as well. 1,000 ha of highly productive forests were cleared in the floodplain area. By now, this area could have produced (since 1986) 17,000 m³ timber a year (Magas *et al*, 1994). The actual production of timber of the Szigetköz area is 40-45,000 m³ (*Table 5.4*).

Table 5.4: The size and the timber production of the forests of the Szigetköz before the Project and currently

	Before the Project	Actual
Forest area (ha) *	8,600	7,600
Yearly timber production (m³/year)	50,000-60,000	40,000-45,000

* mainly used for timber production

5.3.4 IMPACTS OF VARIANT C

Two years passed since the unilateral river diversion. All the effects, damage and extra expenditure caused by this action have been registered by researchers and by the affected forest authorities as well. Two years are too short in the life of a forest, consequently the actual observations should be supplemented by sound predictions of the future. Because of the large groundwater level drop caused by the diversion of the Danube and the drought conditions, reduction of circumference increment of the trees occurred especially in drier places. The consequences of the diversion of the Danube can be observed, for example, in the Dunasziget and Dunakiliti sampling area (*Figure 5.2* and Halupa, 1993).

Most damage have been demonstrated in the forests of the active floodplain, where 93 percent of the trees (poplar and willow) requires additional water which, could not have been provided due to the 2-3 m decrease of the groundwater level (see *Chapter 3*). The lack of the fertilising effect of the flood also contributed negatively. Accordingly:

1) willows started to decline and die along the banks of the main channel (*Plate 12, Volume 1*);

2) reduced growth and impoverished health condition of the trees has been registered;

3) rodents proliferated, secondary pests became abundant.

In forestry operation, transportation became more difficult and much more expensive. The former aquatic transport facilities had to be replaced by terrestrial vehicles and machines. The Szigetköz area (hundreds of islands) is not easily accessible any more, the length of road per hectare is less than one metre in the active floodplain. Transportation length also increased, since the wood-working industry is located along the shore-line of the Danube.
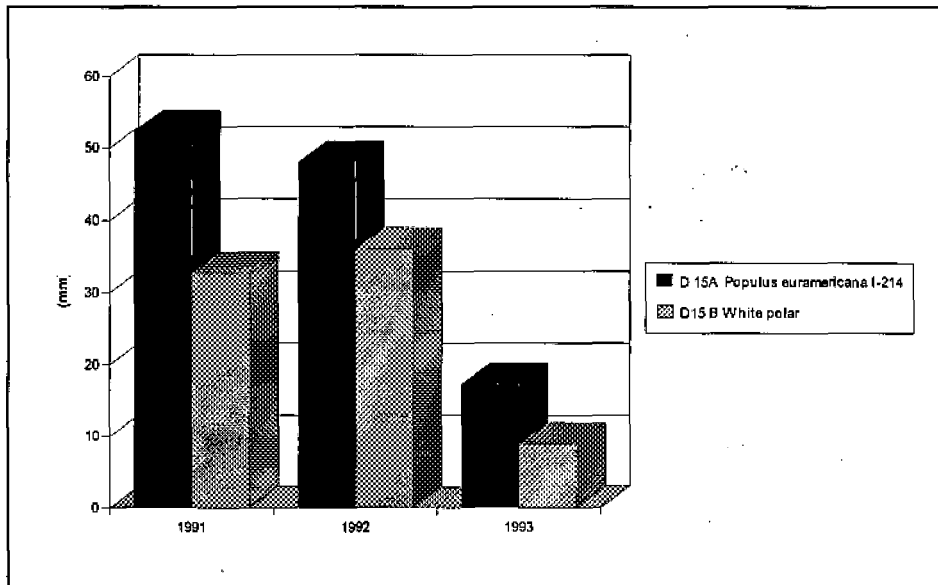
Figure 5.2*: Circumference increment of trees in the Dunasziget experimental forest in 1991, 1992 and 1993*

Legend:
- sapling production
- loss of growth
- pest prevention
- mortality due to drought
- restructuring
- transportation
- game management
- territorial exchange
- quality loss
- plantation

Values shown on chart: 2,063 2,000 1,976 10,219 1,800 3,920 974 3,108 2,236 26,832
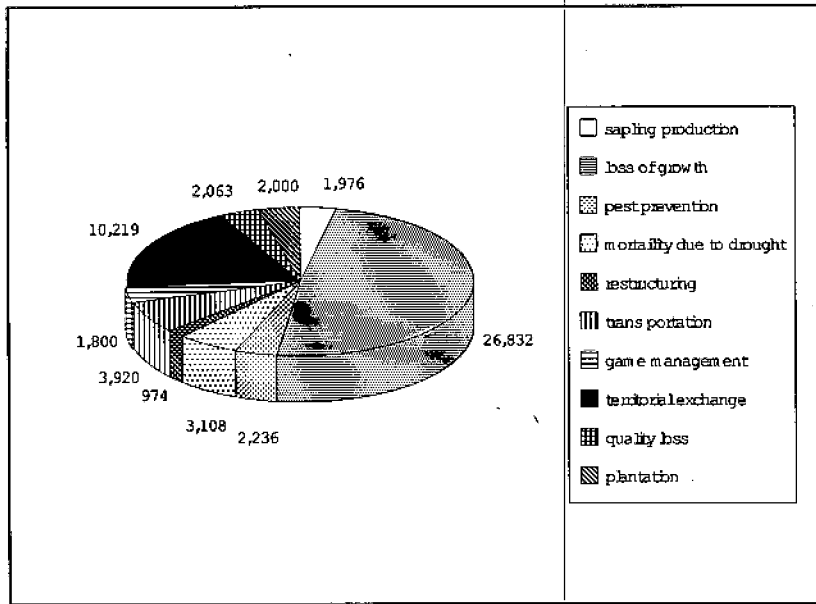
Figure 5.3: *Extra costs and losses of the two years following the diversion – units in thousands of HUF (Magas et al., 1994)*

Figure 5.3 shows the distribution of the estimated cost of damage to the forestry of the two years following the diversion of the Danube. The total volume of extra cost of the two years is 55 million HUF (Magas *et al.*, 1994).

5.3.5 EVALUATION OF REMEDIAL MEASURES

Remedial measures were implemented fairly quickly to supply water to the oxbows and canals of the old floodplain (flood protected area). The "active" floodplain could only get some water (6 m^3/s) first of all in the summer of 1993 (*Chapter 3.2*). These measures provided only negligible effects on the nearby forests.

Regular pumping of 15 m^3/s water from the main channel to the side-arm system started in August 1994. Its effect on the forests could not have been demonstrated so far.

5.3.6 CONCLUSIONS

All forests of the Szigetköz require the direct or indirect effect of the Danube water. This had been provided by the relatively high and fluctuating groundwater level, the water of the floods, and the nutrient rich sediment deposited by the regular floods. The floods also eliminated many pests in the soil.

These floodplain habitats are exceptionally productive and have been intensively exploited by improved hybrid-poplars in the last decades. This favourable situation was first radically upset by the construction work reducing the valuable forested area and interfering with the aquatic transport of the forestry. Then the deviation of the Danube discharge into Slovak territory created a real catastrophe to the floodplain forests. Substantial damage has been demonstrated and further losses are likely to occur. If the presently well balanced age distribution of the trees cannot be maintained because of general (age independent) decline, the ecological and economical balance of the region will be violated for centuries, independently of any water management optimization.

5.4 FISHERY

by Gábor Guti

SUMMARY

The study evaluates the impact on fish under the Gabčíkovo-Nagymaros Barrage System–the effect of changes in flow and sediment regime in the waters of the floodplain. It reviews the impacts of the Original Project in aspects of fishery and the changes in the fish populations of the Danube predicted by Slovak scientists in 1981. The commercial and recreational fishery statistics presented, as well as some estimated biomass data, verified the detrimental effects of the Gabčíkovo-Nagymaros Project on fish. The most important impacts and the forecast damage in relation to the operation of Variant C, are summarised as a reduction of the fishery potential of the Middle Danube.

5.4.1 THE NATURAL SYSTEM

The great variability of the longitudinal, transversal and vertical dimensions of the fluvial fish hydrosystem in the Little Danubian Plain resulted in the development of a diverse potamic biocoenoses unique in Europe. Before river regulation, the longitudinal variability used to manifest itself in a high gradient, turbulent section upstream of the Little Danubian Plain, a shallow braided stretch, and a low gradient, deeper downstream section. The transverse dimension includes the branches, dead arms and wetlands, that is, all the aquatic, semi-aquatic and terrestrial ecosystems within the alluvial plain, which were interconnected with the lotic environment of the river. The vertical dimension includes the alluvial subterranean waters and their organisms. (see *Chapter 4*).

These systems played a prominent part in the regulation processes of fluvial communities. For instance, in the spawning season numerous fishes of the main stream migrated instinctively against the current, sometimes covering a distance of 100-200 km, before they found a suitable habitat for reproduction. Due to the Alpine flood regime of the Danube (see *Figure 3.1*), the low region of the Szigetköz area was flooded during the early summer inundations, where migrating fish could spread out. The slow flowing large branch systems functioned not only as ideal spawning and nursery habitats for the fish species of the Middle Danube, but they were also places where these fishes sought refuge during winter, strong floods or periods of high pollution. Furthermore, the lentic waters of the branches were particularly favourable to the intensive production of plankton and a large part of the planktonic production drifted into the main channel providing an important food source for fish.

5.4.2 HISTORICAL DEVELOPMENT

River regulation since the 19th century impacted on the morphodynamics of the Danube channel as well as its floodplain (see *Chapter 2.2*). Due to the confinement of the inundated area, the closure of the side-arm entrances, the degradation of the main channel, etc. (see *Chapter 2.2*) the ecological conditions have changed considerably, especially in recent decades. This has resulted in detrimental effects on fishery:

1)' *Temporal changes in flow*: Disruption of spawning patterns through inappropriate stimuli or unnatural short-terms flows resulted in changes in community structure from seasonal spawners to species with more flexible spawning. Reduction of the duration of the inundations reduced phytophil spawners because their juveniles were stranded in isolated pools.

2) *Prevention of flooding by dykes*: Loss of floodplain area for spawning, loss of habitat variability, changes in species composition with loss of obligate floodplain spawners. General reduction in productivity of the whole system.

3) *Increased rate of silt deposition in the floodplain* (Dunai, 1992): Reduction of habitat and community diversity, choking of substrates for reproduction leading to failure to reproduce in litophil spawners.

In fishery aspects, the natural waters of the Szigetköz have belonged to the "Előre" Commercial Fishing Company of Győr from 1951 till the present day. The company has a 2,418 ha fishing area on the main stream of the Danube (1850-1770 rkm) and its branch systems, and 730 ha on the Mosoni Danube. As a part of the Danube connected water network another 646 ha is utilised for fishing on the lower section of the tributaries of the Mosoni Danube (*Rába, Marcal, Rábca*)

(Jancsó and Tóth, 1987). Besides the commercial company 28 local sport-fishing clubs háve fishing rights in the Szigetköz and another 96 ha fishing area belongs only to recreational fishery (Bertalan, 1994).

The catch of the commercial and recreational fisheries has been documented since 1967 and 1968, respectively. The statistical data collected for fishery reasons are not suitable for the scientific analysis on the composition of the fish communities. However, as a result of a continuous and extensive sampling, they provide an opportunity for a moderate evaluation of fish abundance and distribution.

Species composition of commercial and recreational catches from 1968 to 1993 (see *Plate 5.2, Volume 5*) indicate the changes of the fish populations in the Danube section between Rajka and Budapest. The most striking is the moderate decrease in the pike (*Esox lucius*) catch and significant increase in the barbel (*Barbus barbus*) catch. Pike is a seasonal phytophil spawner adapted to laying its eggs on submerged plants or riparian vegetation in early spring. Its spawning habitats were restricted by the decline of inundations of the floodplain, therefore its natural recruitment decreased. Barbel is a litophil spawner, its eggs are attached to stones. For spawning, it requires a clean bottom composed of gravel mixed with sand and pebbles. However, contrasted with pike it is a more flexible spawner in space and time and the human impacts did not cause significant reduction of its population. Although the increased rate of silt deposition in the floodplain waters limited its habitats, this species could find suitable sites for spawning in the main stream and the catch of this species has increased since the beginning of the 1980s.

5.4.3 IMPACTS OF THE ORIGINAL PROJECT ON FISHERY

In the 1980s water engineering works connected with the construction of the Gabčíkovo-Nagymaros River Barrage System caused disadvantageous changes in the aquatic habitats. Structures (cross-dams, ditches, etc.) related to the planned water replenishment system of the branches in the Szigetköz floodplain, made the flushing of the side-arms more difficult and accelerated their siltation.

As a consequence of the coffer-dam at Nagymaros, which surrounds the construction area of the planned barrage, the narrower Danube bed resulted in higher current velocity.

These impacts caused the following damage in aspects of fishery:

1) *Cross-damming of branches*: Changes in the flushing rate and deposition of organic sediment resulted in anaerobic conditions in the deeper sections of the side-arms leading to fish mortalities. Interruption of migratory pathways by cross-dams eliminated the migratory fish by preventing movement to floodplain breeding sites by adults and slowing the downstream movements of juveniles.

2) *Increases in flow velocities at Nagymaros*: The higher velocity created an unsuitable condition for the passage of fish.

Before the operation of the Gabčíkovo-Nagymaros Barrage the statistical data for commercial and recreational fishery indicated a decreasing trend of catch in the Danube section between Rajka and Komárom (see *Plate 5.3a, Volume 5*). The reduction was 53% in the main stream of the Danube and its branches; and 75% in the Mosoni Danube from 1988 to 1992. In this period the number of sport-fishermen increased and number of professional fisherman did not decrease significantly. Fishing intensity was the same or slightly increasing on the basis of proportion of the commercial and recreational catches (see *Plate 5.3b, Volume 5*), therefore the decreasing trend of statistical data indicate a considerable reduction of the fish populations as a consequence of the cross-damming of branches.

Slovak scientists (Holčík, 1981) made a detailed prognosis for completing the Gabčíkovo-Nagymaros River Barrage System from a fishery point of view. They estimated in the region between Dunakiliti and the mouth of the Ipel river including almost 86% of the total area of the Slovak Danube section, that there are almost 97% of all fish and about 99% of all the available fish production and it provides almost 92% of the overall fish yields. The most important section of the entire region lies between Bratislava and Palkovičovo and despite the fact that it makes up only 28% of the total area of the Slovak Danube, it contains about 55% of the overall fish biomass and provides 58% of the overall annual available production.

In the region between the Hrušov and Nagymaros Reservoir the total water area would increase from 11,889 ha to 17,224 ha, i.e., 45%. However, from the view point of fishery potential the hydrological conditions of individual biotopes are more important, than the size of the area.

With the Gabčíkovo-Nagymaros Project, the total fish biomass would decrease in the entire region between Bratislava and Nagymaros by 57%, available production by 75%, and the possible yield by 92% (Holčík, 1981). In accordance with an estimate of 1979 these parameters would be 57%, 69% and 89%, respectively (Daubner, 1981). The section which would be the most affected is that adjacent to the Old Danube bed, where the total losses in all parameters exceed 95%.

The Danube section between Bratislava and Nagymaros would have only a minimum biological importance, and fish populations of both the upstream and the downstream Danube sections would considerably decrease (Holčík, 1981). This prognosis does not consider the effects of water level fluctuations caused by peak operation of the Gabčíkovo-Nagymaros Project, and any additional increase in pollution whose magnitude and effects can not be predicted.

The riparian ecotones (interface zones between the aquatic and the terrestrial ecosystems in rivers) have an important role in the recruitment of fish populations,

as spawning and nursery sites, feeding habitats, etc. The peak operation of the Gabčíkovo-Nagymaros Project would result in very high daily water level fluctuations in the downstream section at Gabčíkovo. The rapid fluctuation would destroy the fluvial communities in the ecotones and diminish the productivity of the whole system.

The huge volume of water flushed down in the bypass canal would dam up the flow in the upstream section of the Old Danube twice a day causing considerable damage to the fish populations as observed in the summer of 1994 (see below). The changes in velocity resulted in the accumulation of silt and toxic wastes leading to fish mortalities. In the hot summer period anaerobic conditions would result in the death of fish.

5.4.4 IMPACTS OF VARIANT C ON FISHERY

Measured damage

After October 1992, when the Danube was diverted to the Gabčíkovo power canal, fish populations which assembled in their winter habitats could not always follow the recession of the water. During the first three weeks of the diversion, according to a governmental expert investigation (FH, 1993), the estimated quantity of fish that perished in the Szigetköz branch system was at least 100 tons (80% small cyprinid fish, 10% zander, 5% carp, 3% pike, 2% catfish). The damage (see *Plate 13, Volume 1*) was estimated at 15-21 million HUF (140,000-196,000 USD) at market prices.

As the side-arms gradually dried out, fish remaining in the crowded muddy pools became easy prey for water birds and wild-boar and an accessible catch for the occasional poacher. In the second half of the winter of 92/93 the shallow pools froze solid because of the extensive, low temperatures, which considerably harmed the opportunity for over wintering of the fish. According to moderate estimates, 50 tons of fish died because of the above mentioned reasons during the winter of 1992-1993. The damage was 7-10 million HUF (65,000-93,000 USD) at market prices.

According to the estimate of the Agricultural Office of Győr-Moson-Sopron County (1993), the reduction of the available fish production could be 75% on the Danube between Bratislava and Komárom, as well as in the rivers of the Little Danubian Plain (*Rába, Rábca, Marcal*), but in the Upper Szigetköz it could be as high as 90%. The potential loss of catch (commercial and recreational fishery) could be 100 tons per year. Its gross value is 15-20 million HUF (140,000-185,000 USD).

The commercial and recreational catch decreased by 19% (from 69 t to 56 t) in the Danube section between Rajka and Komárom in 1993. The supposed reduction of

fish biomass would have been higher, but in accordance with the general opinion of some experts, fishing was more efficient in the extraordinarily low water level of the Upper Szigetköz than it had been in the previous year.

At the end of July 1994 there was considerable fish destruction in the main stream of the Danube between Dunakiliti and Nagybajcs (1842-1802 rkm). Its probable reasons were the very long hot period and the extreme low water level. On 30 July a huge volume of water flushed down into the bypass canal at Gabčikovo and the discharge dammed up the water in the upstream section of the Danube in the Szigetköz. The flowing of the main stream stopped and triggered the fish deaths. On the basis of the damage survey of the Agricultural Office of Győr-Moson-Sopron County 15 tons of fish perished (0.2 ton zander, 0.3 ton carp, 0.5 ton asp, 4.0 tons of barbel and 10.0 tons of other cyprinid fish). Their value was 1.5-1.7 million HUF (14,000-16,000 USD) at market prices.

After the catastrophic fish mortalities in the Szigetköz, the Fishery Management Fund of the Ministry of Agriculture gave financial support for fish introduction to the local fishery company. The amount of aid was 6 million HUF (56,000 USD) in 1993 and 3 million HUF (28,000 USD) in 1994.

Table 5.5: *The damage of the fishery in the Szigetköz area since the implementation of Variant C*

DAMAGE	ESTIMATED VALUE (MIN-MAX)	
	million HUF	thousand USD
Fish killed (November 1992)	15-21	140-195
Fish killed (winter 1992-93)	7-10	65-93
Fish killed (July 1994)	1.5-1.7	14-16
Potential loss of catch (1993)	15-20	140-185
Potential loss of catch (1994)	15-20	140-185
Fish introduction (1993)	6	56
Fish introduction (1994)	3	28
Total	62.5-81.7	583-758

Forecast of damage

In recent years the ichthyological field studies of the Hungarian Danube Research Station, Hungarian Academy of Sciences concentrated mainly on the Cikola branch system and made quantitative estimates concerning the fish biomass related

to the conditions in 1992 and 1994 in the relevant stretch of the Danube: between rkm 1838-1832.

The spatial and temporal distribution of fish communities in the flowing waters is quite heterogeneous, so the quantitative study of fish populations is one of the most difficult questions of ichthyological research in the large rivers. The estimate of fish biomass is more reliable if the calculations are separated in accordance to functional units of the hydrosystem. The functional units of the Szigetköz floodplain were classified by the system of Roux *et al.* (1982) (see *Chapter 4.3.2.2* and *Plate 4.3, Volume 5*). All of the side-arms were categorised on the basis of aerial photographs, field experiments and the results were discussed by water management engineers.

Slovak ichthyologists intensively investigated the quantity of fish stocks in the Danube by the mark and recapture method (Holčík and Bastl, 1976, 1977 and Holčík, 1981). The estimate of the fish biomass related to the conditions in 1992 in the Szigetköz area was based on mean biomass density data determined by Holčík (1991). When the status was described in 1994, the biomass density data were corrected with the catch per unit effort data estimated by the Hungarian Danube Research Station.

In the Cikola branch system the side-arms form a dense network; their length is five times more than the length of main channel. The surface area of the branches and the main arm was 318-390 ha at medium water level in 1992 and in some previous years. On the basis of their morphology the side-arms have the following categories:

1) *eupotamon*, that is large running waters;

2) *parapotamon*, that is semi-stagnant arms, where the downstream end is still connected to the river;

3) *plesiopotamon*, that is temporary standing branches with no permanent connection to the river;

Plate 5.4a (Volume 5) shows the distribution of these functional units and *Table 5.6* summarises the estimate of the fish biomass.

Table 5.6: Estimated fish biomass in the Cikola branch system (rkm 1832-1838), before the implementation of Variant C (status prior to 1992)

Biotope	Area (ha)	Proportion (%)	Biomass (kg/ha)	Total biomass (tons)
eupotamon	159-195	45-55	30-40	4.77-7.80
parapotamon	139-171	40-48	200-370	27.80-63.27
plesiopotamon	20-24	6-7	600-1400	12.00-33.60
Total	318-390			44.57-104.67

Since the implementation of Variant C, or rather since the diversion of the Danube at Čunovo, the Cikola branch system has been strongly influenced by the reduction of the river discharge, and has had its functional units changed as well. In August 1994, when the major part of water replenishment was provided by pumping, the surface area of the Cikola-branch system was 232-285 ha, this meant that 86-105 ha of the side-arms were dry. In that condition the wet channels have four categories:

1) eupotamon, that is, the main channel of the Danube;

2) lotic parapotamon, that is, slowly flowing arms (0.5-0.6 m/s);

3) lentic parapotamon, that is, stagnant waters which have direct contact with the lotic arms;

4) paleo-plesiopotamon, that is, isolated standing waters with no permanent and direct connection to the other arms.

Plate 5.4b (Volume 5) shows the distribution of these functional units and *Table 5.7* summarises the estimate of the fish biomass.

The area of the wet side-arms decreased by 25-30% compared to the situation in 1992 at medium water level. During this period the changes of the hydrological conditions of biotopes resulted in the decrease of the total fish biomass by 56-64% on the basis of calculations.

These calculations indicate the trend and the order of change in the Cikola branch system. The biomass density and proportion of the functional units are different in other sections of the Danube in the Szigetköz, therefore the extrapolations of estimated data would be difficult to the whole floodplain or to the fishing areas.

Table 5.7: Estimated fish biomass in the Cikola branch system (rkm 1832-1838), after the implementation of Variant C, when the major share of the water supply was provided by pumping (August 1994)

Biotope	Area (ha)	Proportion (%)	Biomass (kg/ha)	Total biomass (tons)
eupotamon	148-182	58-70	30-60	4.44-11
lotic parapotamon	55-67	21-25	100-300	5.55-20
lentic parapotamon	18-22	7-9	300-600	5.40-13.20
paleo-plesiopotamon	11-14	4-5	50-150	0.55-2.10
Total	232-285			15.94-46.32

The medium and long term damage to fisheries is higher than the calculated losses. The structures of the water supply system have blocked of the branch systems in

the Szigetköz and there is no direct connection between the floodplain habitats and the main riverbed. The Alpine character of the flood regime does not exist anymore and the hydrology of the side-arms changed. The flow through of the branch systems is only 1.5-2 days annually every 5-10 years and the full inundation is to be expected once in every 10-25 years (see *Chapter 3.2*). Since the operation of the Gabčíkovo Barrage, the water transparency has increased and flow velocity has decreased in the side-arms. This condition is favourable for the high production of submerged aquatic vegetation.

The impacts mentioned have caused the following damage in aspects of fishery:

1) *Blocking of the branch systems*: Loss of floodplain habitats for spawning, nursery, feeding and wintering result in a considerable decrease of fish production. Fishery potential of the Szigetköz area will decline. Lack of large-scale fish recruitment has detrimental effects on the fish populations of the Middle Danube for a few hundred kilometres downstream.

2) *Changes in flood regime:* Subsequent reduction of habitat diversity, loss of species, diminishing productivity at community level due to the switch from the Alpine character flood regime to stable system dynamics.

3) *Decrease of flow rate*: Shifts from rheophilic to limnophilic communities in the side-arms. Changes in flushing rate resulting in accumulation or low dilution of toxic wastes or anaerobic conditions leading to fish mortalities.

4) *Decrease in suspended silt load:* Water transparency is higher. Increase in density of submerged aquatic vegetation leads to an increase in the abundance of phytophil fish. Changes in fish community, that is a reduction in number of the non-visual predators and omnivores. Risk of fish mortality due to anaerobic conditions caused by eutrophication.

5) *Diversion of water into the bypass canal*: The higher discharge in the tail-race canal directs the shoals of fish during their spawning migration to the tailwater of the Gabčíkovo Barrage, which is an insurmountable barrier and the bypass canal is an unsuitable habitat for spawning.

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CHAPTER 6

SEISMOLOGY AND EARTHQUAKE ENGINEERING
by Anthony Bracegirdle

SUMMARY

Seismic design parameters for the Project were decided in 1965. At this time, design input parameters were based largely on historical data. In the late 1970s probabilistic methods and, more recently, deterministic methods of assessing seismic hazard became accepted into current practice. Substantial advances in design methods have also occurred over this period. It is now widely recognised that assessments based simply on historical records of earthquakes underestimate the risks associated with large, critical developments which have the potential for widespread damage in the event of failure.

No systematic re-zoning of the project on the basis of current practice has taken place since 1965, although a large number of useful background studies have been undertaken. In terms of global seismology, the region is characterised by moderately low rates of energy release. Simple risk assessments, for example ICOLD (1989), suggest that the project would fall into a high risk category; projects in high risk categories are usually designed to avoid an uncontrolled release of water in the event of a realistic maximum credible ground motion being felt. The selection of maximum credible ground motions should be realistic, conservatively assessed on a rational basis. For the purpose of review, the effects of a Richter magnitude, M=6.5, earthquake acting within source zones, identified by recently assembled macroseismic, geophysical and geological data, have been considered. The water-retaining dykes of the headrace canal and the Dunakiliti-Hrušov/Čunovo Reservoir have been identified as particularly vulnerable; liquefaction, settlement leading to over-topping, and uncontrolled release of water are likely to occur under the criteria adopted in this review.

It is apparent that the potential problems associated with seismic risk have not been adequately addressed, either during design or subsequently. It is concluded that there were significant grounds for concern over seismic design standards and other unresolved problems at the time when Hungary suspended construction of the project. A potential weakness in the detailing of the Variant C dykes has been identified. The interface between dykes and structures are often critical in seismic design, and these have not been checked or commented on in this study. The need for an immediate full and systematic analysis of risk and dam safety remains, although background studies have been carried out by Hungary.

6.1 INTRODUCTION

6.1.1 EARTHQUAKE RISK

Earthquake risk can, in simple terms, be viewed as the product of damage potential, exposure to hazard and the vulnerability of the structures. The Gabčíkovo-Nagymaros Project, as perceived at the time of the Treaty in 1977, comprised an extensive system of dykes and the construction of three major barrages over a 160 km stretch of the Danube. The dykes provide containment of the impounded waters upstream of the barrages, which were to have been located at Nagymaros (km 1696), Gabčíkovo (adjacent to km 1821) and Dunakiliti (km 1842). Any damage that would occur as a result of a breach of the dyke system (i.e., flooding, economic damage, loss of life, etc.) would vary from location to location and in some areas this could be quite severe.

The rate of release of seismic energy in the region is relatively low when compared to more active areas in Europe, such as Central Italy and Southern Greece. As a consequence, the frequency of large earthquakes is difficult to establish with any certainty. It is apparent from historical records that the region is capable of producing strong shaking, albeit infrequently. The great geographical extent of the project is such that the integrated exposure to seismic hazard for the whole project would be substantially greater than that of a single element of the scheme.

The construction of the dykes varies from location to location, although the use of the Danube gravel as bulk fill is relatively widespread throughout the Project. By its nature, the Danube gravel is easily eroded by water and, as a result, a breach would develop quickly if the integrity of the water retaining system were impaired. Under strong earthquake shaking, dykes and embankments may become vulnerable to lateral spreading, settlement and consequent over-topping.

The dykes of the Project are likely to provide the highest risk due to earthquake shaking because they are exposed to hazard over a large area, they are potentially vulnerable, and the consequences of over-topping and failure are likely to be severe in some locations. A full study of risk would normally be required under present-day standards for major projects. Such a study would be extremely complex and is beyond the scope of this report. Design parameters for earthquake shaking were provided in the Joint Contractual Plan. This report discusses the containment dykes and their design in relation to our present understanding of the seismological environment and potential vulnerability of these structures.

6.1.2 PROJECT OUTLINE

6.1.2.1 Nagymaros Reservoir

In the Original Project, barrages would have been provided at Nagymaros, Gabčíkovo and Dunakiliti. The barrage at Nagymaros was to be integrated with power generation facilities and ship locks. Under normal operating conditions the water level upstream of Nagymaros would have been about 6 m above the level of the river under average flow conditions (Q=2300 m^3/s); operating water levels would have been above river bank level for a distance of 30 to 40 km upstream of the barrage, the effects of impoundment extending as far upstream as Gönyü (100 km upstream). Containment dykes would have been provided principally by the raising and strengthening of existing flood protection dykes of the Danube and its tributaries, the Ipoly (Ipel) and Hron Rivers. Substantial geotechnical problems were identified in relation to raising the water level upstream of Nagymaros by Mantuano (1989); these problems were not fully resolved at the time Hungary suspended construction at Nagymaros.

6.1.2.2 Gabčíkovo Structures

The barrage at Gabčíkovo incorporates ship locks and power generation facilities; a 17 km-long headrace canal extends upstream to the Hrušov Reservoir. The water level in the headrace varies between about 7 m and 15 m above the level of the surrounding land, giving an impounded volume for the headrace of about 80 million m^3.

The containment dykes of the headrace are constructed with bulk fill, comprising compacted Danube gravel and an upstream bituminous concrete membrane. A freeboard of 2.0 m is provided between the operating levels of the canal and the crest of the dykes. In order to avoid post-construction settlement, the Joint Contractual Plan called for the removal of 2 to 3 m of clayey and silty soils from the foundation of the dykes. The excavation of about 2 m of soil, extending to up to 5 m where peaty, silty or clayey soils were found was confirmed by Liška (1994). Polko (1993) maintained that an assessment of liquefaction potential of the foundation was made, and unsuitable material removed during the course of construction; no data was presented to illustrate the investigations or the analyses that were carried out. This view was echoed by Hydro-Quebec International (1990), but again no data were provided. This view is strongly contested by Finta (1990), who maintains that considerable difficulty was experienced with the excavations and that insufficient fine-grained material was removed. The allegations made by Finta are of great concern and require investigation.

6.1.2.3 Dunakiliti-Hrušov Reservoir

In the Original Project it was envisaged that the closure of the Old Danube course would be made near Dunakiliti, and a barrage incorporating a spillway, control gates, and a ship lock would be built on the site of the closure. The Dunakiliti-Hrušov Reservoir was intended to have an impounded volume of about 200 million m^3, of which 49 million m^3 is contained over a depth of 1 m below operating level. The containment dykes comprise new gravel-fill structures with upstream blankets of fine-grained soils or asphalt, and strengthened existing flood banks. The greatest retained height of water would have been about 7 m above river bank level, near Dunakiliti. I have no information that an attempt was made to remove liquefiable materials beneath the dykes of the Dunakiliti-Hrušov Reservoir; this is supported by construction drawings provided by OVIBER (1994) and investigations carried out by Eötvös Loránd Geophysical Institute (ELGI, 1991).

6.1.2.4 Čunovo Reservoir and Variant C

Between 1991 and 1992, the Slovak developers constructed the "Variant C" headrace linking Gabčíkovo to a reservoir formed by the closure of the Danube at Čunovo. The Variant C dyke is similar to those forming the headrace constructed under the Joint Contractual Plan, except that water-proofing is provided by a PVC membrane within the retained-water side of the dyke. The membrane is covered by 1.5 m of fill at a slope of 1:3; the fill is protected by a geotextile cover and precast concrete anti-erosion slabs.

The Čunovo Reservoir utilises dykes constructed for the Dunakiliti-Hrušov Reservoir; the resulting impoundment is less than planned under the Joint Contractual Plan, although the length of the critical headrace canal is extended by approximately 9 km.

6.1.3 DAMAGE

The consequences of a breach of the dykes would be most serious at the following locations: immediately upstream of Nagymaros, in the Gabčíkovo Headrace and in the lower reaches of the upstream reservoir. I am not aware of any systematic study of the dyke-breach scenario; it is evident however, that local communities are likely to be inundated (Perczel and Libik,1989).

Although the volume of water impounded by the scheme is large, the relatively low height of the dykes and high flood flows in relation to the impounded volume should be taken into consideration in assessing potential damage. Flood damage that occurred in 1954 and 1965 would provide useful guidance in generating dyke-breach scenarios as part of an assessment of risk. The large volume of water impounded in the headrace canal is, however, of particular concern as this is held

above the level of the surrounding land, and not within the confines of the old river channel. Sound operating procedures, in the event of an earthquake or flood, and contingency plans could substantially mitigate potential damage. It is, however, clear that, at present, there are no risk strategy plans or operating procedures which are mutually agreed between Hungary and Slovakia.

A simplistic evaluation of potential damage using the criteria of the International Commission on Large Dams (ICOLD, 1989) would place the scheme in categories III or IV (the classification extends between I and IV in increasing level of severity; categories III and IV are considered high risk categories). In a preliminary analysis of risk, using probabilistic methods, return periods for earthquakes could be taken as 1 in 10,000 years (category III) and 1 in 30,000 years for category IV (for example, see Charles *et al.*, 1991). Critical or high risk structures, even in areas of relatively low seismicity, are preferably designed on the basis of deterministically evaluated ground motions; catastrophic failure as a result of ground motion arising from a Maximum Credible Earthquake (MCE) should be prevented. The MCE is defined as the earthquake that would cause the most severe level of ground motion which appears possible for the prevailing geological and tectonic conditions.

6.2 GEOLOGICAL AND TECTONIC BACKGROUND

6.2.1 BASEMENT STRUCTURE AND CRUSTAL MOVEMENT

The most important feature of basement structure of the Little Hungarian Plain is the Rába-Hurbanovo Line. The line separates pre-Tertiary (older than 65 million years) rocks of the Alpine-Carpathian metamorphic series to the NW of the Line from the Transdanubian Range Unit to the SE, and is effectively a boundary between micro-plates. A programme of detailed geological mapping has been undertaken in this area since 1982 (Don *et al.*, 1993), and extensive geophysical mapping as part of the DANREG project carried out since 1989 (Verő and Nemesi, 1994). The Rába-Hurbanovo Line has been identified as running NE from Győr towards Kolárovo in Slovakia and then to the east through Hurbanovo.

A deep (8,000 m) basin is observed in the pre-Tertiary basement rocks between Győr and Dunakiliti to the NW of the Rába Line. The centre of the basin is situated near Gabčikovo, the principal axis of the basin running NE-SW (see *Plate 6.1, Volume 5*). Very weak Tertiary rocks comprising calcareous clays and weakly cemented sands and gravels fill the basin. This is the result of crustal subsidence, which has been very vigorous in the past and has continued and perhaps accelerated in the Quaternary (i.e. the last 2 million years). Current rates of crustal subsidence are estimated at about 2.0 mm/year within the basement area (Joó, 1994 and Don *et al.*, 1993). The predominant Slovak view is that the basement beneath the Gabčikovo area is divided by NE-SW and NW-SE oriented faults; blocks of basement rock within this area which are delineated by the faults are

sinking relative to the surrounding rocks. This view is outlined in the Joint Construction Plan, and described in detail by Mantuano (1989). Janaček (1971) describes a major NE-SW fault running sub-parallel to the Rába line through Gabčíkovo. The potential capability for movement of these faults was considered a sufficient hazard by the designers to justify relocation of the Gabčíkovo barrage 700 m upstream to its present location; this decision was made on the basis of investigations made after design, and prior to the commencement of work at Gabčíkovo. A number of studies have been carried out by the Hungarian scientific community (for example, Verő and Nemesi, 1994 and Balla, 1994) in order to examine the potential of faulting in this region to produce shaking. The principal conclusions of these studies are:

1) Faults in the immediate vicinity of Gabčíkovo are unlikely to produce strong motions, and are poorly defined by macroseismic data.

2) A fault line exists between Komárom and Győr , which is well defined by geophysical, geological and macroseismic data. The fault is considered capable of producing strong motion.

Excavations for the foundations of the Nagymaros barrage were carried out prior to 1989. The excavations revealed predominantly andesitic rocks that had been greatly distorted by tectonic activity (Bence *et al.*, 1991 and Gálos and Kertész, 1990). Although no direct evidence was found for movement along these faults in the overlying Quaternary deposits during excavations for the Nagymaros facility, geological comparison of the level of gravel terraces of Quaternary age along the Danube in this region show that tectonic movements have taken place in this period. The capability of faults in this area is also supported by macroseismic and geodetic data; their capability cannot be ruled out (Balla, 1994).

6.2.2. SEISMICITY OF THE REGION

Earthquake intensity relates to physical damage observed as a result of an earthquake. Unless otherwise stated, intensity is in this report quoted in terms of the MSK scale; this is a 12 point scale, directly comparable and equivalent to the older MCS scale. Intensity may be related by empirically-based relationships to Richter magnitude, M, which is an instrumental measure of the energy released in a seismic event (see *Chapter 6.3.1.1*).

Considerable research on historical earthquakes in Hungary was carried out by Réthly (1952), who compiled a list of events that occurred between 455 and 1918. Other studies, for example Ribárić (1982), have assisted in assessing historical seismicity for the region. Since the turn of the century a more systematic approach to data collection and retrieval has been in place such that most events of epicentral intensity, I_o, greater than about 3.0 have been recorded. The completeness of the record diminishes with time prior to 1900, particularly in relation to small events.

The Hungarian Earthquake Catalogue (456-1986), prepared by Zsíros *et al.* (1989), lists the historical and more recent instrumental data for the region. It is worth noting that of the 5,000-plus number of earthquakes listed for the Carpathian Basin, only 17 relate to the first 1,000 years of the record; of these, 14 have estimated values of I_o of 8 or greater. In the subsequent 500 years a total of 49 earthquakes of I_o of 8 or greater are listed. It is probable, on this basis, that the early historical record is deficient even in respect of large events.

Despite the difficulties with completeness of the historical record, it is evident that the present rate of energy release is relatively low when compared to more active regions of the world. In regions of low rates of energy release it is extremely difficult to assess a tectonic framework with certainty, and this uncertainty will be carried forward in the assessment of seismic hazard. Macroseismic data is, however, extremely useful in identifying potential earthquake source zones.

In order to carry out probabilistic analyses on earthquake recurrence, Zsíros (1991) proposed 14 source zones, which were based primarily on macroseismic data (see *Figure 6.1*). Of these source areas, the most active in Hungary is that extending south of Komárom, towards Berhida (Zone 1, *Figure 6.1*). The strongest recorded event within this source was the 1763 Komárom earthquake which is listed as having an epicentral intensity of 9±1 MSK and an estimated Richter magnitude of 6.2 (refer to Zsíros *et al.*, 1989). Other estimates of epicentral intensity range between 8.5 and 9.5 (Szeidovitz and Mónus, 1993 and Szeidovitz, 1986). Zone 11 on *Figure 6.1* represents the relatively active Mur-Mürz Line.

In a recent study, Balla (1994) reviewed potential source zones. He postulates a source zone running east-west between Győr and Becske, sub-parallel to the Hurbanovo Line, as shown on *Figure 6.2*. Evidence for the existence of such a source is found in macroseismic, topographic and geophysical data. The known fault between Győr and Komárom represents the most active section of this source, several hundred earthquakes having occurred on this line since 1754. Balla (1994) maintains that the 1763 Komárom earthquake is not necessarily related solely to the Komárom-Berhida source, but could be related to the Győr -Becske Line. This view is supported by historical research, Szeidovitz (1986), which shows isoseismals for the main shock around an axis lying east-west, parallel to the Győr -Komárom fault. In addition, the main shock was preceded by fore-shocks in the vicinity of Győr . Macroseismic data collected between 1989 and 1993 (Zsíros, 1994) show a small event (I_o=3.5) in Komárom in 1989 and similar sized events near Győr in 1990 and 1993. It should be noted that Dunakiliti lies within 30 km of the Mur-Mürz source, Gabčíkovo within 20 km of the Győr-Becske source, and Nagymaros within the Győr-Becske source.

A few fault plane solutions exist for Hungarian earthquakes. These are predominantly strike-slip mechanisms. There is, however, little data to sensibly assess maximum credible events on the basis of anything other than a probabilistic approach. Kárník (1971), of the Czechoslovakian Academy of Sciences, outlines the

results of a Gumbel analysis of seismicity in the Carpathian region. The analysis utilises data from the whole region and concludes that the largest "possible" event is of Richter magnitude 6.5, having a probability of excedence of 1%. A similar value was obtained independently by Kárník using simple empirical deduction. A refinement of this assessment is embodied in the "Scheme of Earthquake Provinces" produced by Kárník *et al.* (1978), which shows a maximum earthquake strength of Richter magnitude 6.0 (see *Figure 6.3*). At present there is insufficient information to allow a fully deterministic evaluation of the Maximum Credible Earthquake; earthquakes of between 6.0 and 6.5 magnitude (Richter) remain appropriate in light of more recent studies, and it is considered that an event within this range of magnitude could conceivably take place anywhere within the source zones identified.

6.2.3 QUATERNARY DEPOSITS

The Quaternary period extends from 1.64 million years before the present to the present day. The period is sub-divided into the Holocene (0 to 10,000 years before the present) and Pleistocene (10,000 years to 1.64 million years before the present); the division being made on the basis of climatic change. Holocene deposits are often referred to as "recent" and represent a greater risk of liquefaction or cyclic mobility under earthquake shaking than older deposits.

The Quaternary deposits between Nagymaros and Komárom are relatively complex and comprise interbedded clays, gravels and sands, with raised gravel terraces on higher ground to the south of the river. The overburden immediately upstream of Nagymaros is generally about 10 m in thickness, increasing with distance upstream.

A deep basin filled with Quaternary deposits extends beneath the Danube between Bratislava and Komárom. The Pleistocene materials comprise the Gabčíkovo Sand and the overlying Danube gravel, and reach a total thickness of up to about 600 m in the centre of the basin. The relatively permeable Danube gravel is 12-15 m thick at Bratislava, increasing to about 100 m at Dunakiliti, and to about 300 m at Gabčíkovo. The Danube gravels are typically in the fine to medium range, with a variable content of fine and medium sand. These materials are unlikely to be susceptible to liquefaction or settlement during shaking.

The Holocene materials vary in composition and thickness across the Danube alluvial cone. At Dunakiliti they are typically 5 m to 7 m in thickness, and increase to about 30 m in thickness near Gabčíkovo (Don *et al.*, 1993). They comprise clayey silts, silty sands, fine sands, sand/gravel mixtures and can contain layers of peat. The thickness and nature of these materials can vary considerably over a short distance, particularly where in-filled side-arms or channels are met.

I have reviewed cone penetration test data made available by ELGI (1981, 1991) which are considered representative of the Dunakiliti-Hrušov area. Typical traces of cone resistance within the Holocene deposits are shown on *Figure 6.4*. As can

be seen from *Figure 6.4*, cone resistances in fine sands and silty sands are frequently in the range 1-4 MPa, indicating these materials to be extremely loose. Such materials are potentially liquefiable during strong earthquake shaking when present at depths of less than about 15 m: whether or not liquefaction takes place is dependent on the severity of the ground motions, and this is discussed further in *Chapter 6.3.2*. I have not seen data comparable to that provided by ELGI for Slovak territory in the vicinity of Gabčíkovo, or other data that would allow a comprehensive assessment of liquefaction potential in this area. As the depositional environment at Gabčíkovo has been broadly similar to that at Dunakiliti, I would expect similar materials to be present at Gabčíkovo, but in greater thickness.

6.3 EARTHQUAKE ENGINEERING

6.3.1 SEISMIC ZONING OF THE PROJECT

6.3.1.1 Earthquake intensity

The seismicity of the region was discussed by a joint meeting of Czechoslovakian and Hungarian experts in September 1965. During this meeting, levels of earthquake intensity and design levels of acceleration were set for various parts of the project as outlined in *Table 6.1*. The Intensity Scale applied at this time was the twelve-point MCS (Mercalli-Cancani-Sieberg) Scale, which is summarised in *Table 6.2*. The MCS Scale was adopted by the International Seismological Association in 1917. The MCS classification proved to be rather imprecise and made little allowance for local building practice. Levels of ground motion associated with the MCS scale are often those of early building codes. Improvements were made, and the American Modified Mercalli Scale (MM, 1931) and the European Medvedev-Sponheuer-Kárník (MSK, 1964) Scales were introduced. The MSK and MM Scales are twelve-point scales like the original MCS Scale; as outlined by the World Data Centre A for Solid Earth Geophysics (1979), the grades of the three scales are equal and equivalent to each other. In addition, a new European Macroseismic scale (EMS), which is a revision of the MSK scale, has recently been accepted by the European Community (1992).

Use of the MCS Scale has persisted in Italy and Greece, although in neither country is it currently embodied in design codes.

Table 6.1: Seismic Zoning for the Project, September 1965.

River Section (river km)	Design Intensity I_o (MCS)	Design Acceleration (g)
−1861	7	0.025
1861-1823 (Dunakiliti)	6	0.01
1823-1808 (Gabčíkovo)	7	0.025
1808-1797	8	0.05
1797-1770	8.5	0.08
1770-1764 (Komárom)	9	0.10
1764-1752	8.5	0.08
1752-1740	8	0.05
1740-1720	7	0.025
1720-	6	0.01

The instrumental determination of magnitude, for example the Richter Scale, offers a more consistent approach cataloguing earthquake strength. The bulk of historical data was gathered before instrumental determinations were possible, and hence intensity scales continue to be of importance in decision-making. Correlations between epicentral intensity, I_o, and Richter magnitude, M, have been attempted for the Carpathian region by Csomor and Kiss (1959):

$$M = 0.6I_o + 0.3$$

$$M = 0.6I_o + 1.8 \log h - 1.3 \text{ (h: depth of focus)},$$

and more recently by Kárník (1966):

$$M = 0.56I_o + 0.96$$

As can be seen by Kárník's regression analysis, which is shown on *Figure 6.5*, there is considerable scatter in the data. Only broad comparisons are, therefore, advisable; nevertheless, it can be seen from *Figure 6.5* that the "maximum possible" event for the region, $M_{max}=6.0-6.5$, prescribed by Kárník is broadly consistent with $I_o=9$ MCS or MSK.

Table 6.2: *Mercalli Cancani Sieberg (MCS) Intensity Scale.*

	Class	I_o	Effects
I	"IMPERCEPTIBLE"	1	Can be detected only by instruments
II	"VERY LIGHT"	2	Detected only in the upper floors of buildings by particularly sensitive persons
III	"LIGHT"	3	Detected only by few persons, similar to vibrations produced by a fast car passing nearby
IV	"MODERATE"	4	Detected by many persons inside houses and by a few in open spaces, with vibrations similar to those produced by a heavy lorry. Slight trembling of dishes in cupboards.
V	"QUITE STRONG"	5	Detected by practically everybody; swaying of suspended objects, visible movement of trees and branches.
VI	"STRONG"	6	Detected by everybody with alarm; many run outside. Moving and falling of certain objects; cracks in the mortar of a few houses.
VII	"VERY STRONG"	7	Considerable damage from falling objects; large bells ring in churches. Slight damage to solid houses, localised destruction in old houses.
VIII	"DESTRUCTIVE"	8	Bending and falling of trees. Serious damage to about 25% of buildings. Streams carry sand and mud.
IX	"STRONGLY DESTRUCTIVE"	9	Destruction and severe damage to about 50% of buildings.
X	"RUINOUS"	10	Destruction of about 75% of buildings, of some bridges and dams. Landslides.
XI	"CATASTROPHIC"	11	General destruction of buildings and bridges, including piles. Significant morphological changes and many landslides
XII	"TOTALLY CATASTROPHIC"	12	All works of man are destroyed. Great morphological changes. The course of rivers is changed and lakes disappear.

As can be seen from *Table 6.1*, the highest design intensity, I=9, occurs near Komárom; it is comparable to the 1763 earthquake, and that postulated by Kárník as the "maximum possible" for the region. The seismic zoning proposed in 1965 is very similar to zoning embodied in Czechoslovakian building codes, described by Kárník *et al.* (1988). The zoning applied in the building codes for "standard" buildings is based purely on historical earthquake events. As noted by Kárník *et al.* (1988), this approach is not satisfactory for "critical facilities" for which a "more

complex hazard assessment must be made". This is particularly true in regions of low rates of energy release where earthquake source zones and recurrence relationships are poorly defined.

6.3.1.2 Design acceleration

The design accelerations given in *Table 6.1* are directly comparable with earthquake coefficients given in Romanian and Yugoslavian (1964) building codes (refer to I.A.E.E., 1984) for the corresponding intensity value. These are compared with peak ground accelerations taken from Spanish, Italian and Soviet practice on *Figure 6.6*. As can be seen from *Figure 6.6*, the design coefficients are approximately 30% of peak ground acceleration.

The design coefficients of the Yugoslav and Romanian codes, and those of the Project, are intended for use in simple pseudo-static design methods. By such methods a "static" force is applied to the structure being analysed, and the stability of the structure tested against simple equilibrium criteria. Because peak ground acceleration refers to the single largest instantaneous acceleration during an earthquake, it would not be appropriate to use peak ground acceleration in such analyses. In the 1970s and 1980s, advances were made in dynamic analyses, which consider the full time-history of earthquake records. Earthquake records are best scaled to meet design requirements according to peak ground acceleration, velocity and duration, which can be measured in the field, and to which the attenuation relationships (ground motion v. distance) can be fitted. Typically, pseudo-static design coefficients are between 20% and 30% of peak ground acceleration. Increasingly, pseudo-static coefficients are not provided directly in building codes but are incorporated into multipliers applied to peak ground acceleration. Dynamic analyses, on the other hand, use peak ground acceleration directly. Relationships between peak ground acceleration and intensity were available at the time the design criteria for the Project were set (for example, see Medvedev, 1962 and *Figure 6.6*). I believe that the acceleration levels embodied in the Joint Contractual Plan were not intended as a measure of peak ground acceleration. Intensity 9 MCS would, for example, have a design coefficient of 0.10 g (see *Table 6.1*), corresponding to a peak ground acceleration of about 0.30 g (see *Figure 6.6*).

6.3.2 METHODS OF EVALUATING EARTHQUAKE HAZARD

6.3.2.1 Probabilistic methods

Probabilistic methods provide a means of evaluating seismic hazard at a specific site. They were introduced by Cornell (1968), and are based on the historical record of earthquakes, applying the following procedure:

1) Earthquake source zones are identified and recurrence relationships (earthquake magnitude v. return period) established for each source.

2) An attenuation relationship (earthquake motion v. distance from the epicentre) is developed or a relationship for a similar tectonic region is adopted. In this case, earthquake motion is characterised by peak ground acceleration.

3) A cumulative probability distribution is constructed from (1) and (2) above, combining the contributions from the various sources.

4) The probability of varying levels of acceleration occurring or being exceeded is calculated assuming an extreme event probability distribution for the expected design life of the facility.

Probabilistic methods suffer a number of drawbacks. As discussed previously, the identification of source zones may be difficult in areas of low rates of energy release, particularly where there is little surface expression of the sources. Recurrence relationships, which are based on a relatively short historical record, become inaccurate when calculating the probability of extreme events with return periods of 10,000 years or more. In addition, it is assumed that earthquakes are uniformly distributed in space and time within the source zones, which is not necessarily true.

A probabilistic analysis was carried out by Zsíros (1991) on the Dunakiliti facility using the source zones shown in *Figure 6.1*. The results of the analysis are shown in *Figure 6.7*. As can be seen from *Figure 6.7*, the design level of intensity (I=7) would be expected to have a return period of about 1,000 years; this corresponds to a 10% probability of excedence over a 100 year period, and I know of no circumstances where this could be shown to be acceptable for large critical structures.

6.3.2.2 Deterministic methods

In the deterministic approach, earthquake sources are identified, and the effects of earthquakes of varying magnitude occurring at the closest point within the various sources to the site are assessed. Because of the difficulties associated with probabilistic analyses, preference is give to deterministic methods in current practice (ICOLD, 1989). Ideally, appropriate real time histories should be used and consideration be given to the local soil conditions in evaluating the site response. Such an analysis has been carried out using strong motion data from the 1976 Friuli earthquake by Bondár (1994). The Friuli earthquake was used because the mechanism is appropriate to the region (i.e., shallow strike-slip), the earthquake recording was made on outcropping basement rock, and the magnitude appropriate to the analysis. The analysis considers the effect of a magnitude 5.6 earthquake at an epicentral distance of 25 km. A soil column 400 m in thickness was used,

having properties appropriate to the Danube gravel and overlying Holocene materials. The properties are estimated rather than measured; future work should, where possible, be based on measured data. The analysis is, however, regarded as sufficient for present review purposes. The calculated ground response showed a peak ground acceleration of about 0.25 g.

The study by Bondár (1994) forms a useful basis for comparison, as the event size approaches that of the "maximum possible" given by Kárník (1971) and the epicentral distance is comparable to both the distance of Gabčíkovo to the Győr-Becske Line (Balla, 1994) and the distance of Dunakiliti from the Mur-Mürz Line.

The concept of designing critical facilities to maximum credible ground motions evolved during the 1970s and 1980s, and was embodied in ICOLD recommendations in Bulletin 72 in 1989. Bulletin 72 states: *"For dams whose failure would present a great social hazard, the maximum design earthquake will normally be characterised by a level of motion equal to that expected at the dam site from the occurrence of a deterministically evaluated maximum credible earthquake....It will be required at least that the impounding capacity of the dam be maintained when subjected to that seismic load."* A detailed risk analysis is, however, required to determine whether this level of design is justified. Such an analysis, using present "state-of-the-art" techniques, has not to my knowledge been carried out. The decision concerning seismic design input parameters should be made jointly by the owners, their consultants and involved regulatory or review agencies, with a strong consideration of public sentiment. When considering the physical size of the project and the number of communities close by, and since the project occupies an international border, it is likely that the use of a Maximum Credible Earthquake would be shown to be appropriate.

In this particular case, a sensible basis for review would be to apply an agreed "maximum possible" earthquake anywhere within the potential source zones (Mur-Mürz and Győr-Becske Lines). The study by Bondár (1992) indicated a peak ground acceleration of about 0.25 g for a magnitude 5.6 earthquake at an epicentral distance of 25 km; a similar exercise using a magnitude 6.5 earthquake is likely to show a higher level of acceleration, probably of the order of 0.3 g, to be applicable to the majority of the project.

I have not seen the results of the investigations of the fault line in the immediate vicinity of Gabčíkovo, which were carried out by the Slovak side. I am therefore unable to comment on the capability of this fault and it is possible that this fault should also be considered as an earthquake source. If included, levels of peak ground acceleration greater than 0.3 g may be applicable to Gabčíkovo.

6.3.3 ENGINEERING DESIGN

6.3.3.1 Containment dykes

Experience has shown that compacted granular embankments are usually inherently stable during earthquake shaking, providing the foundation materials are sound. The use of a rolled asphaltic membrane on the retained-water side, such as constructed in the headrace canal under the Joint Contractual Plan, means that the bulk fill of the dykes remain dry and, hence, less susceptible to settlement during strong shaking. Loss of freeboard due to internal deformation and settlement within the headrace dykes is unlikely to exceed 1% of the height of the dyke at levels of shaking consistent with the Maximum Credible Earthquake (see *Chapter 6.3.2.2*). Settlements of less than 0.2 m can therefore be expected from the internal compaction of a 20 m-high dyke.

The bulk fill of the headrace canal dykes comprises Danube gravel. As described in the Joint Contractual Plan (1978) and by Mantuano (1989), the particle size distribution of the Danube gravel is well-graded and stepped; the gravel content is typically in the range of fine to medium, with significant proportions of fine sands. Medium and coarse-grained sands are virtually absent. Such materials when re-compacted tend to be easily eroded by water and are potentially internally unstable when subject to through-flow of water. Gradings of the Danube gravel that I have examined fail the criteria of Kenney and Lau (1985), which has been shown to reasonably predict internal instability observed both in the laboratory and in the field. In the 1960s and 1970s, such materials were generally considered as stable. The potential vulnerability of these materials is of concern, and increases the risk of a breach of the dykes occurring in the event of damage to water-proofing membranes or over-topping.

The careful detailing of interfaces between concrete structures, such as weirs, and earth structures is essential in ensuring good performance during earthquakes. I have not had access to such details on the Slovak side and recommend that such a review be carried out by an independent review board. I have some concern over the performance in the retained-water membrane detailed for the Variant C dykes. This comprises a 0.6 mm thick PVC membrane covered by a 1.5 m thickness of bulk fill and pre-cast concrete wave protection units. My chief concern is that strong shaking would be accompanied by down-slope sliding of the fill overlying the membrane. This would cause cracking and settlement at the crest of the dyke, and possibly rupture of the membrane; in this case, the membrane supplies a low-strength surface for the overlying fill to slide on.

6.3.3.2 Liquefaction of dyke foundation materials

Granular materials, for example silts, sands and gravels, that are saturated with water and in a loose condition may be subject to liquefaction. Soils undergoing liquefaction lose their strength, and this is marked by phenomena such as "sand boils" appearing at the surface and flow-slides. Liquefaction phenomena have been associated with earthquakes in historical data extending back to the 16th century. Technical reports on damage to embankment fills due to liquefaction began to emerge in the 1960s (e.g., Duke and Leeds, 1963). It was not until 1971, with the failure of the Lower San Fernando Dam, that designers began to realise the limitations of pseudo-static design methods which made no allowance for complete or even partial liquefaction of soils. A method of evaluating liquefaction potential was first made by Seed and Idriss (1971). The method, which is based on case histories and the results of standard penetration tests, is still used in current practice. Modifications have since been made to make allowance for earthquake magnitude, the presence of fine materials or gravels and the use of cone penetration tests in place of standard penetration tests (for example, Tokimatsu and Seed, 1987 and Tokimatsu, 1988).

Technical developments in laboratory testing and the dynamic modelling of soils have proceeded concurrently with empirical methods. Sophisticated dynamic finite element modelling is now possible in which pore pressure generation can be assessed, and predictions made of displacement and loss of strength of foundation materials as a result of earthquake shaking.

Liquefaction phenomena have been documented on four occasions in Hungarian history:

1) Komárom (1763) $I_o=9.$

2) Mór (1810) $I_o=7$

3) Érmellék (1834) $I_o=9$

4) Kecskemét (1911) $I_o= 8$ to 9

In practice, such phenomena are not observed at Richter magnitudes of less than 5.0. Although comparatively large (M=7.2), the 1977 earthquake in Vrancea, Romania, is illustrative of the potential problems. The earthquake epicentre was relatively deep ($\approx$100 km), and the effects spread over a wide area. A maximum horizontal ground acceleration of about 0.2 g and intensity, I=8, were measured in Bucharest. As can be seen from *Figure 6.8a*, liquefaction phenomena were widespread, extending up to 200 km from the epicentre. Lateral spreading and loss of freeboard of dykes due to liquefaction were observed, and are shown schematically on *Figure 6.8b*.

As discussed in *Chapter 6.2.3*, the very low penetration resistance of the recent fine sands and silts in the region indicate these materials to be susceptible to lique-

faction. The simple evaluation procedures developed by Seed and Idriss (1971) and Tokimatsu (1988) are based on measured or assumed peak ground acceleration. Bondár (1992) showed that peak ground accelerations of about 0.25 g could be expected about 25 km from an M=5.6 event. Accelerations of 0.3 g probably represent the maximum credible case; liquefaction of the loose sands and silts can be expected when applying the above evaluation methods with this level of acceleration. In the worst credible scenarios, therefore, facilities at Dunakiliti, Čunovo and Gabčíkovo would be just within areas of potential liquefaction surrounding the source zones. Furthermore, the raising of water levels upstream of Nagymaros would have increased the potential for liquefactions in this area as well.

6.3.3.3 Settlement in foundation materials

Granular materials may undergo volume change as a result of earthquake shaking. The degree of volume change is dependent on the dynamic shear strain to which the soils are subject, and the density and grain size of the soils. The volume change results in settlement at the ground surface. Where the degree of shaking is sufficient to cause liquefaction, settlements may be in excess of 1% of the thickness of the liquefiable soil. Liquefaction is, however, not strictly necessary for settlements to take place; settlements of up to about 1% of the thickness of the deposit are possible, without liquefaction taking place.

There have been a number of case studies, the most dramatic of which occurred at the Homer Split during the 1964 Alaskan Earthquake (M=8.5). Measurements showed that settlements amounting to 0.5% (0.76 m) of the 140 m-thick layer of sands and gravels at the site were due to compaction within these materials. In addition, 0.6 m of regional subsidence took place, bringing the total settlement to 1.36 m. Another illustrative case study is the smaller, M=6.3, earthquake in Edgecumbe, New Zealand, in 1987. The earthquake, which had an epicentral intensity of 9, was accompanied by widespread liquefaction over a 200 km^2 area (Smith and Wood, 1989).

There are similarities between ground conditions at Edgecumbe and those in the Szigetköz. Both areas are thought to be located in zones of crustal sinking; rates of sinking around Edgecumbe were about 1-2 mm/year prior to the earthquake (Blick and Flaherty, 1989), which is comparable to that of the Szigetköz. In both areas there are deep basins filled with Quaternary materials. In addition to widespread liquefaction, settlements of up to 2 m were recorded. The fault-plane solution for the main shock has indicated both strike-slip and normal components of shaking, and it is clear from field observations that movements have taken place on several faults, not necessarily within the earthquake hypocentre. The settlement observed was the result of both compaction of the Quaternary soils, and tectonic movement.

Simple methods of estimating compaction settlements have been developed by Lee and Albaisa (1974), Tokimatsu and Seed (1987) and Watabe et al. (1993). At

present, I do not have sufficient information on ground conditions to fully appraise potential settlements. It seems likely, however, that the Danube gravel would not be susceptible to settlement during shaking. If this is the case, then total settlements due to compaction of the overlying Holocene could approach 0.3 m, without liquefaction having taken place. Evidence is, however, required to exclude the Danube gravel as contributing to possible settlement. Settlements of greater than 0.3 m within the foundations of the dykes can be expected where liquefaction and lateral spreading of the dykes takes place. Tectonic sinking would be additional to these movements.

The freeboard allowance applied to the headrace canal is 2.0 m, and is 2.5 m in the lower reaches of the Čunovo Reservoir and the dykes of Variant C. These allowances are broadly consistent with overseas practice. The Soviet SNIP II regulations apply the following relationship in estimating the height of earthquake-generated waves (Δh):

$$\Delta h=0.4 + 0.76(I-6) \text{ (metres)}$$

which gives Δh=2.7 m for I=9. Under the Soviet criteria, the freeboard is possibly too low for the case of the likely Maximum Credible Earthquake. Of concern, however, is the freeboard in relation to settlements that might occur as a result of strong shaking, particularly in view of the potential for liquefaction and settlement as illustrated by observations made during the 1987 Edgecumbe earthquake, the 1964 Alaska Earthquake, and the 1977 Vrancea Earthquake.

6.3.3.4 Geotechnical issues relating to impoundment at Nagymaros

A number of geotechnical problems were identified by Mantuano (1989) relating to the impoundment upstream of Nagymaros. These problems were principally of river bank stability, and the effect of rising groundwater on existing land slipping. Although solutions had been investigated in some areas, other areas remained unresolved. Above Zebegény, rising groundwater would potentially have caused flooding of low lying areas. Prevention of flooding would have required permanent pumping. The economic impact of these geotechnical issues would have been significant, and certainly required evaluation.

6.4 EARTHQUAKE DESIGN

6.4.1 SEISMOLOGY

The seismic zoning for the project was conceived in 1965, and was based simply on historical records of earthquakes in the region. The application of this approach is widely recognised as underestimating the risk associated with large, critical

projects. More recently, probabilistic and deterministic methods of evaluating seismic hazard have been developed, and re-evaluation of the safety of existing dams has been recommended by the International Commission on Large Dams (ICOLD, 1989). A limited application of these methods to the project has confirmed that a revision of the seismic zoning of the original project was necessary. As far as I am aware, no systematic attempt has been made to re-zone the project using methods of hazard evaluation that comply with current practice.

In areas of low rates of energy release, it is often difficult to establish source zones and recurrence relationships that are necessary for carrying out probabilistic analyses of extreme events. In the region, the reliable history of large events is probably no more than 500 to 1,000 years; this is a short time period in relation to extreme events, which may have return periods of tens of thousands of years.

Risk analyses are complicated by the large geographical extent of the project, and the difficulty of assessing economic loss in the case of a breach of the containment system. To my knowledge, a full risk analysis has not been carried out. When considering the size of the project and its location, and importance, a risk analysis would, by present standards, be regarded as mandatory.

Any decision on input parameters for seismic design should be conservative, realistic, and based on sound engineering judgement. A simplistic assessment of risk based on ICOLD Bulletin 72 would probably place the project in a high risk category. This suggests that the structures should be designed to withstand the Maximum Credible Earthquake, without uncontrolled release of the impounded water. Subject to a risk analysis being carried out, a sensible approach for present review is to adopt source zones on the basis of the recent geological, seismological and tectonic studies (for example, Balla, 1994), and apply a worst possible earthquake of M=6.5 within these zones. Site response studies, such as that made by Bondár (1992) should be used to determine input parameters. Consideration should also be given to the potential capability of the fault line located 700 m downstream of Gabčíkovo.

6.4.2 ACCELERATION

The levels of acceleration embodied in the Joint Contractual Plan are for use in pseudo-static design methods, and are not directly comparable to peak ground accelerations which are used in more modern design methods. If earthquake design were based on the concept of Maximum Credible Earthquake, as described in 6.4.1 above, the effect would be similar to applying the original design levels of ground motion for the zone 1770 rkm to 1764 rkm (Komárom) over the entire project.

Pseudo-static design methods are not, however, appropriate in assessing displacement and potential for liquefaction and settlement during earthquakes.

Critical structures should be examined using modern finite element techniques, in which allowance can be made for strain softening of the foundation materials.

Simplified methods used to examine liquefaction and settlement rely on peak ground acceleration; in the case of the maximum credible event, this would be of the order of 0.3 g over much of the project. This level of acceleration is comparable to that applied to large critical structures in other European countries with low levels of seismicity. In the UK, for example, peak ground accelerations of up to 0.375 g are recommended for high risk dams (Charles *et al.*, 1991).

6.4.3 VULNERABILITY AND DAMAGE

Compacted soil embankments with membranes on the retained-water side, as adopted for much of the project, are well suited to resisting earthquake shaking without substantial damage or deformation. From the limited information available it is likely that the level of acceleration expected during the maximum credible event would be sufficient to cause liquefaction of the recent sands and silts. As these materials are known to extend to depths of up to 30 m near Gabčíkovo, it is very unlikely that all liquefiable material was removed during construction of the headrace canal; liquefiable material is also likely to extend beneath the dykes of the Čunovo Reservoir.

Liquefaction beneath dykes would be accompanied by lateral spreading and a reduction of crest height. Other mechanisms such as settlement due to compaction, and tectonic subsidence could also lead to a reduction of crest height, and possibly over-topping. The allowance for freeboard (typically 2 m) is probably adequate to cover seismically induced waves, but may not be sufficient to deal with subsidence of the dyke foundations under extreme earthquake loading. The bulk fill forming the dykes is potentially easily eroded, and overtopping would be very likely to develop into a major breach in a short space of time.

The detail of the water-proofing membrane of the Variant C dyke is also of concern. Under strong shaking materials overlying the membrane could slide on the membrane, causing cracking at the crest of the dyke and possible rupture of the membrane.

6.4.4 CONCLUSION

I have not been able to carry out an exhaustive check on the adequacy of the design details. On checking the basic design concepts, however, I have reached the following conclusions:

> 1) Although consistent with practice in 1965, the methods used for determining the seismic zoning do not comply with current practice;

they do not adequately reflect the importance of the project nor do they meet with modern standards of acceptable risk.

2) There are substantial uncertainties in assessing risk; nevertheless, studies should be carried out to identify and quantify risks. Subject to such a study being carried out, immediate review should be based on the application of a Maximum Credible Earthquake. Liquefaction and settlement beneath containment dykes, loss of freeboard and consequent uncontrolled release of impounded water are likely under this criteria.

3) There were significant geotechnical problems associated with impoundment upstream of Nagymaros that were not fully resolved in 1989.

To my knowledge, a detailed risk analysis has not been carried out. There were certainly grounds for concern over design standards and unresolved difficulties in 1989. These were, in themselves, sufficient to justify a reappraisal of design standards and operating conditions for structures already built. This could, in effect, involve a reappraisal of the economics of the entire project.

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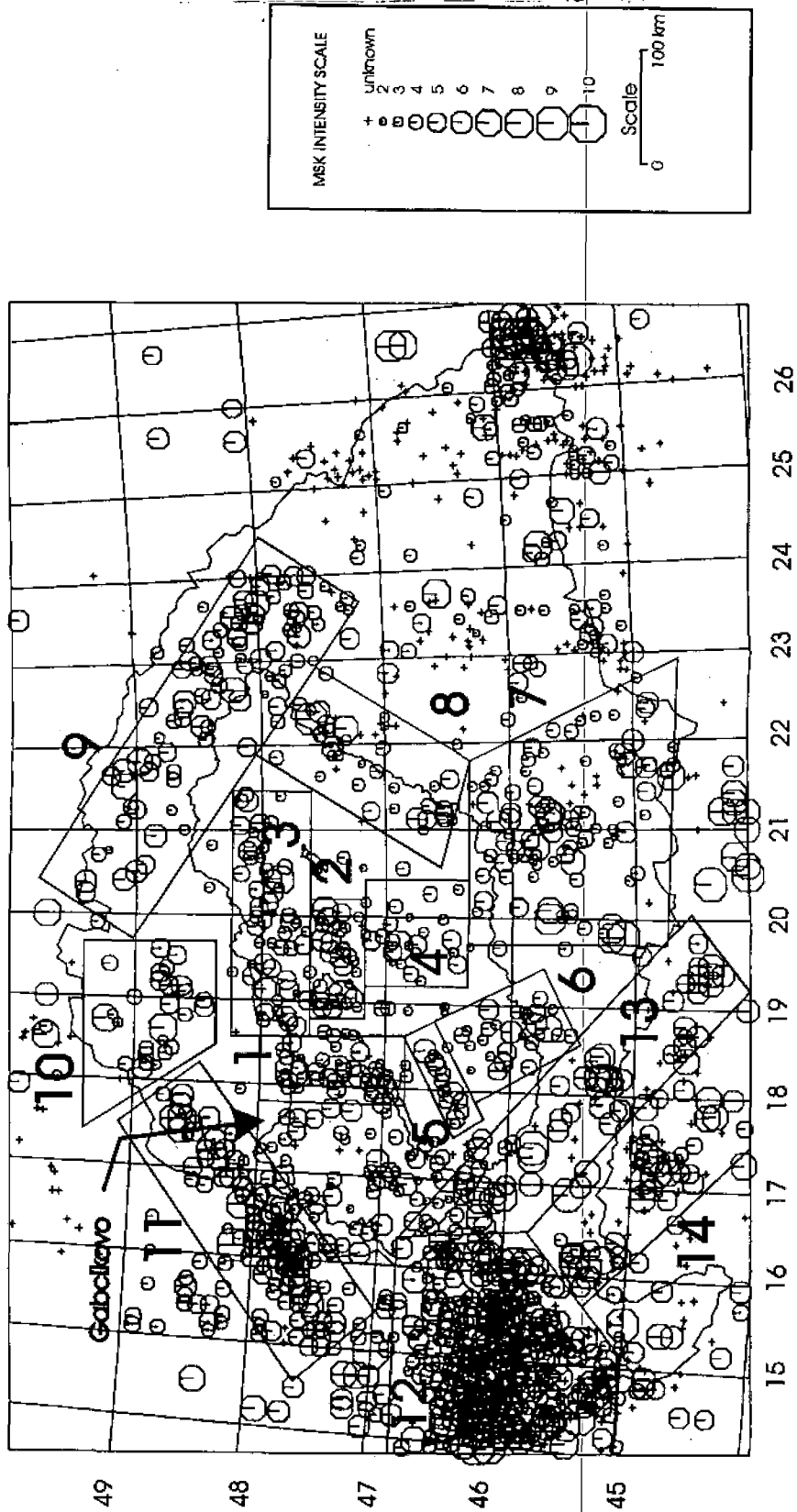
Figure 6.1: Earthquake source zones after Zsiros (1991)
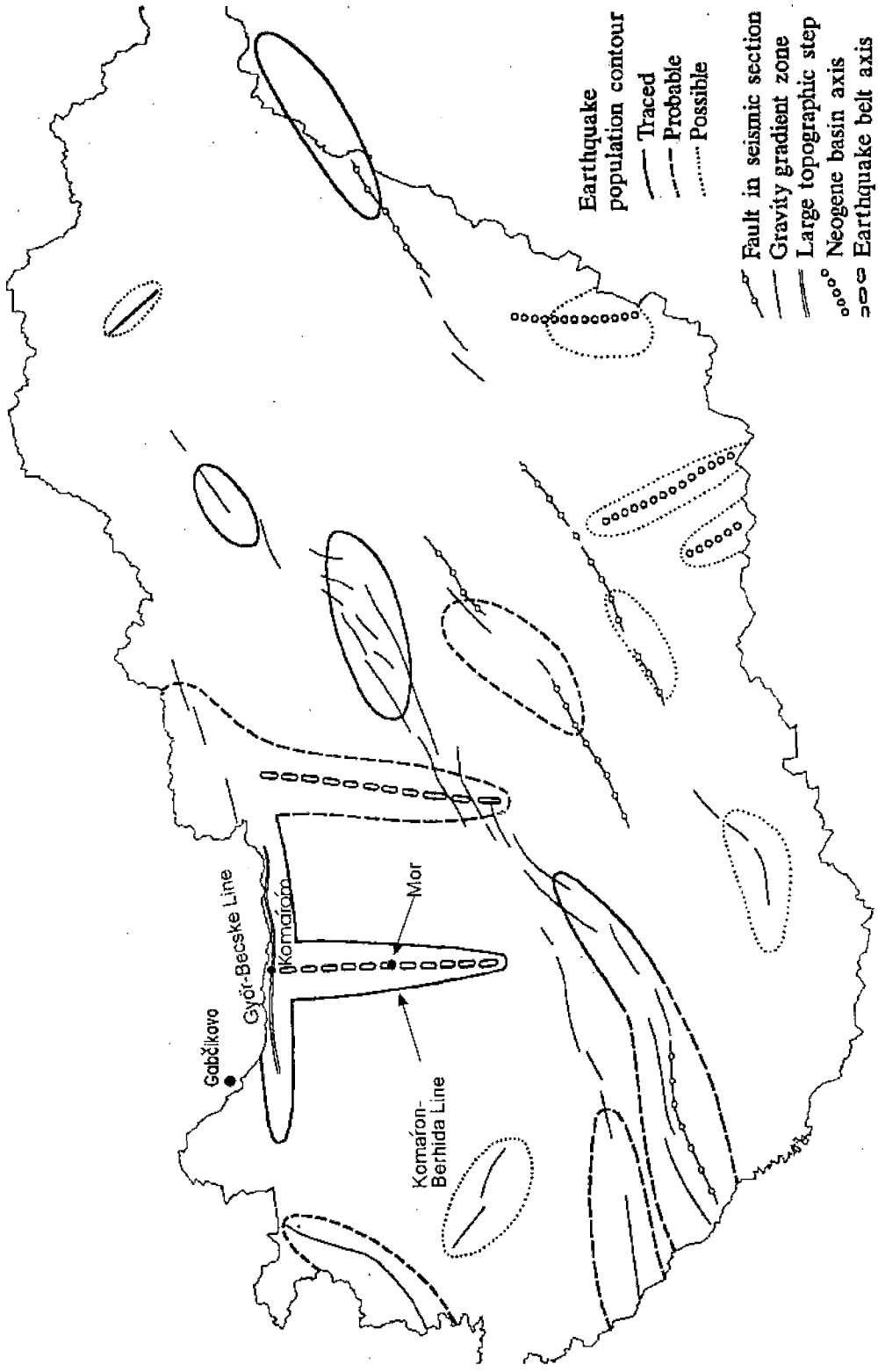
Figure 6.2: Earthquake populations and various lineaments, after Balla and Gaal (1994)
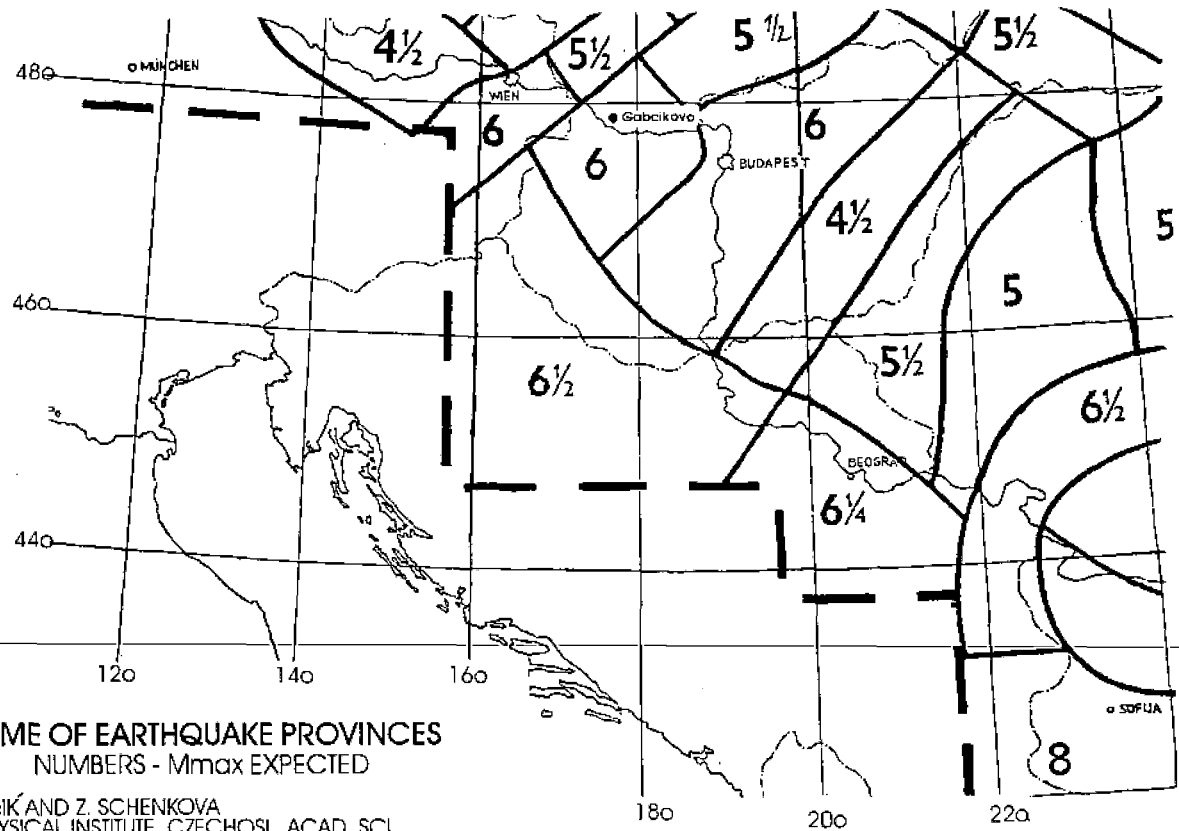
SCHEME OF EARTHQUAKE PROVINCES
NUMBERS - Mmax EXPECTED

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V. I. BUNE
INSTITUTE OF SOLID EARTH'S PHISICS, ACAD. SCI. USSR
1978

Figure 6.3: Magnitudes of worst possible earthquakes after Karnik et al., 1978.
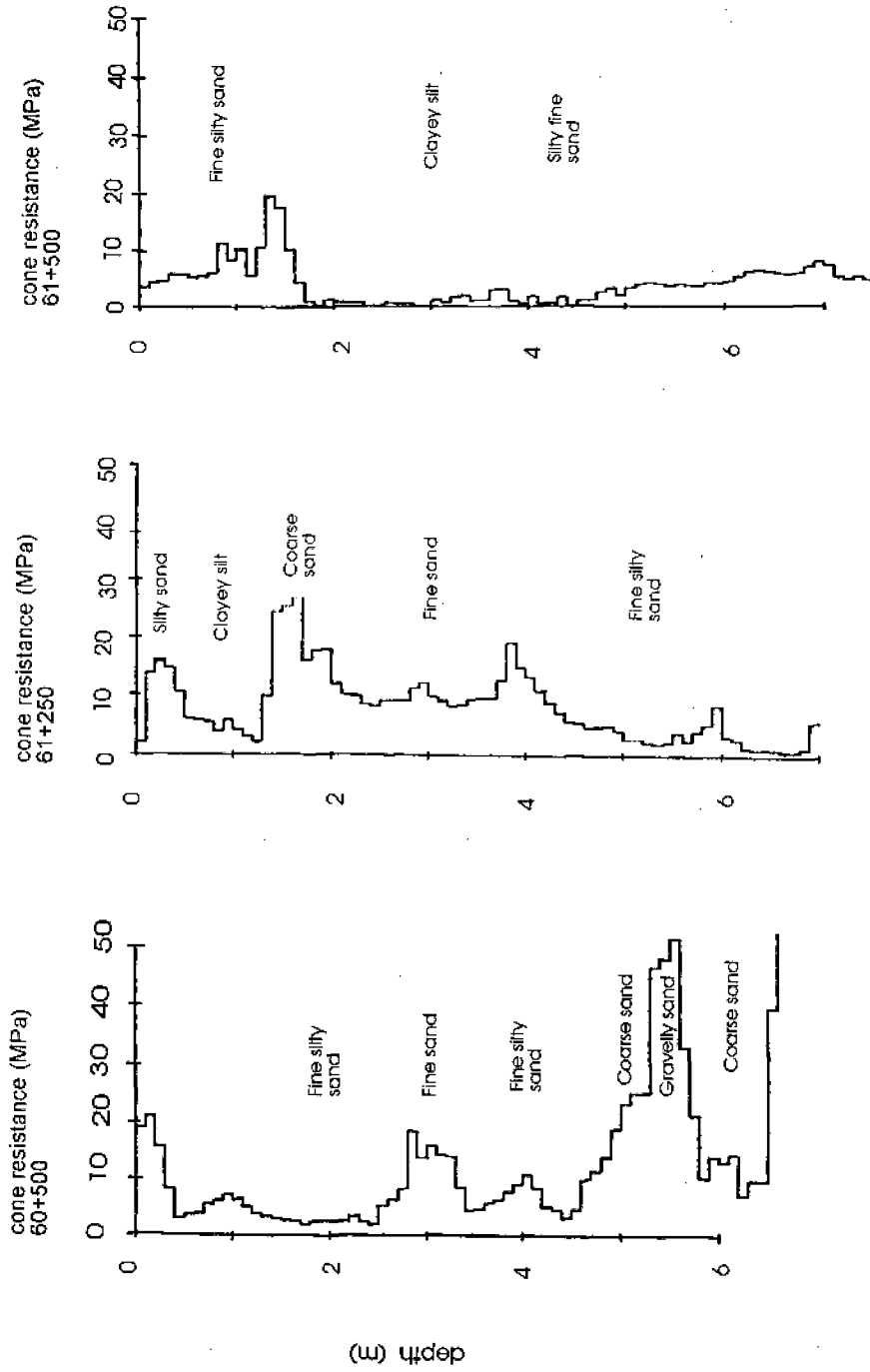
Figure 6.4: Cone resistance versus depth, near Dunakiliti, after ELGI, 1991
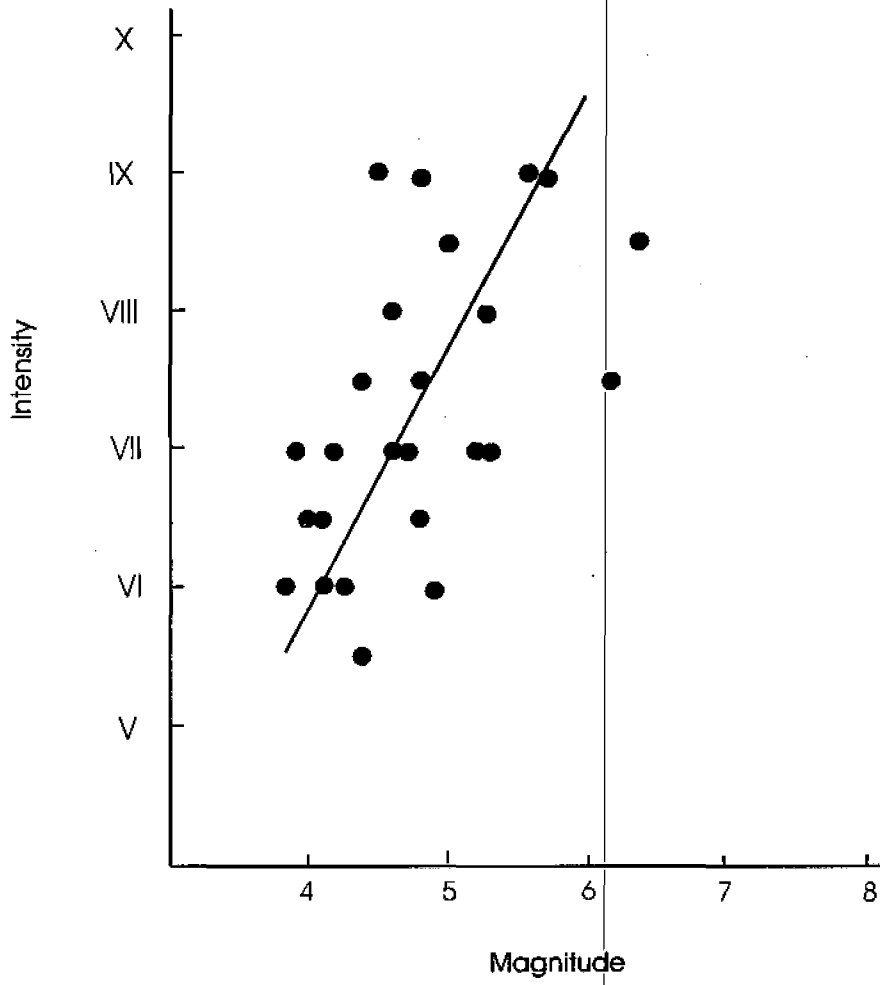
Figure 6.5: Earthquake magnitude versus intensity (after Karnik, 1971)
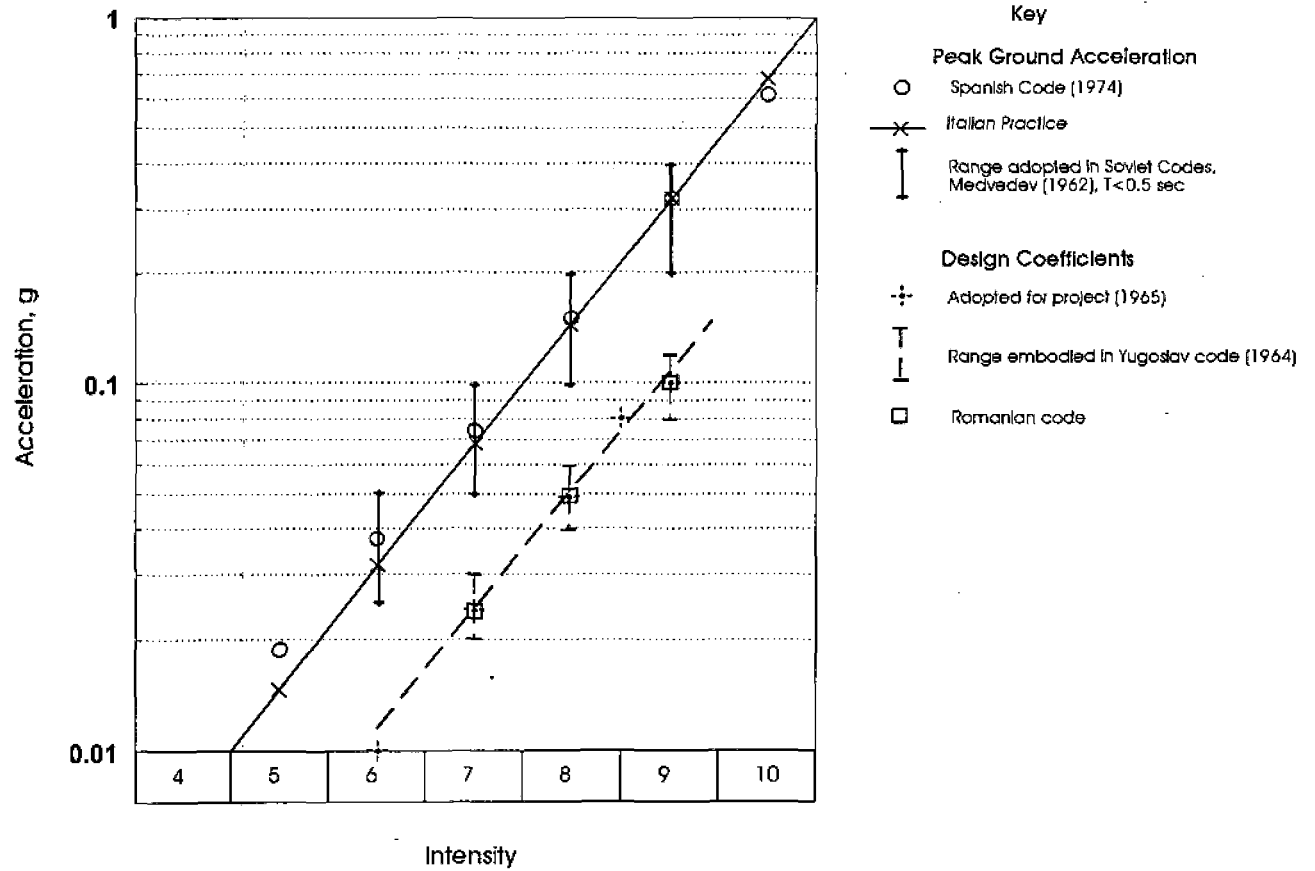
Figure 6.6: Intensity versus acceleration
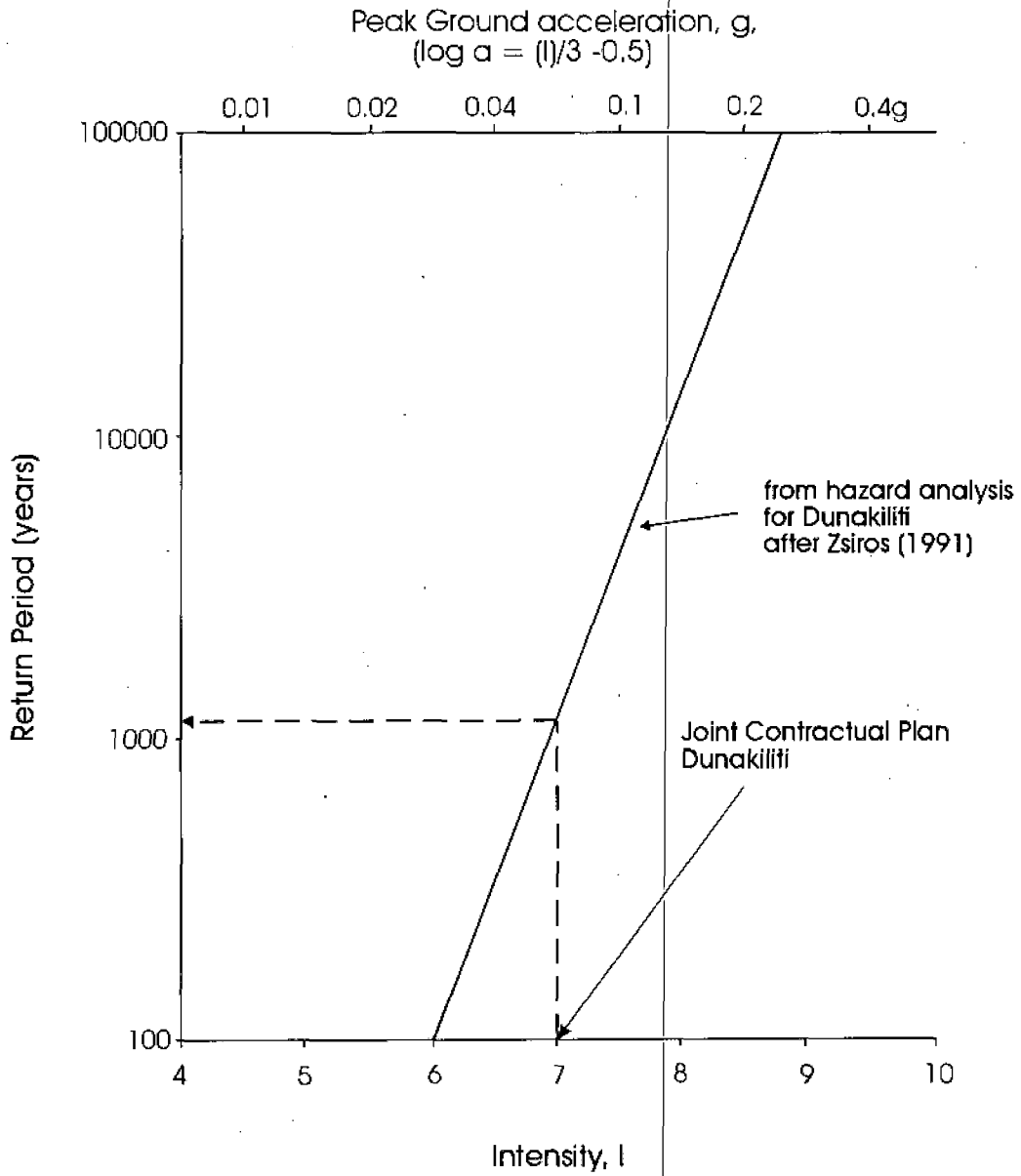
Figure 6.7: *Intensity versus Return period from probabilistic analysis, Dunakiliti, after Zsiros (1991)*
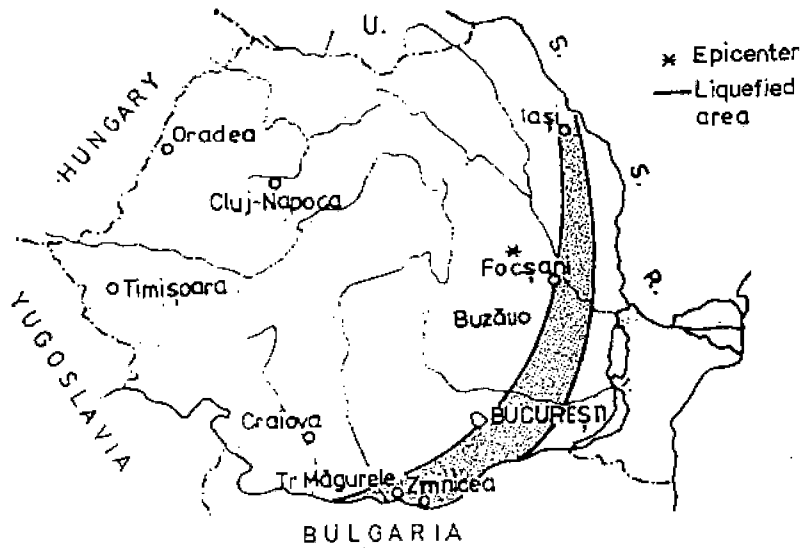
Figure 6.8a: Liquefaction of sandy soils after the Vrancea earthquake March, 1977 after Priscu et al (1985)
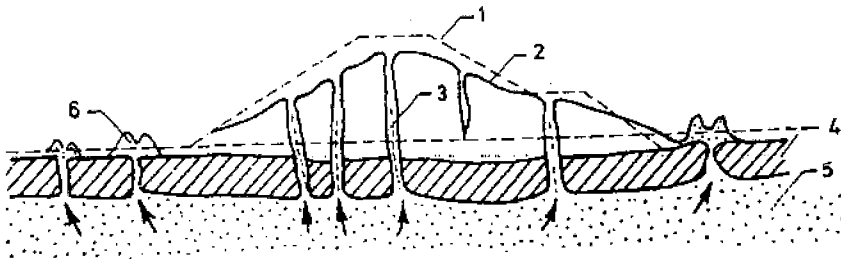
1 - original slope line, 2 - slope line after earthquake, 3 - longitudal cracks, 4 - impervious layer,
5 - liquefiable sand, 6 - sand craters

Figure 6.8b: Damage of dikes caused by ground liquefaction Vrancea, 1977 after Priscu et al (1985)

CHAPTER 7

ENVIRONMENTAL IMPACT ASSESSMENT (EIA)

Luc Hens, Muraleedharan Valappil and Dimitri Devuyst

7.1 THE CONCEPT OF EIA

Environmental Impact Assessment (EIA) is a process for acquiring, analysing and reporting the facts about the social, economic and environmental effects of economic development plans, programs and projects. EIA addresses the constraints and opportunities that the natural environment brings to the success of development. Its aim is to discover problems at an early stage and to provide for their solution so that the benefits of economic growth can be achieved without unacceptable damage to environmental values. It specifies monitoring and post development audits to ensure that environmental predictions are accurate and that implementation of measures and precautions reduces or avoids adverse environmental effects (Carpenter and Maragos, 1989).

The EIA process consists of the EIA procedural steps, the Environmental Impact Statement (EIS), and the link between EIS and decision-making, monitoring and post-development audit. EIA procedural steps include screening, scoping, baseline studies, public participation, prediction and preparation of initial and final EISs, review by public and independent experts, decision-making, monitoring and post-project auditing. An EIS should cover the need for the project and alternative ways to achieve the goal or purpose. It should describe present environmental conditions and the technology to be used, and then predict the consequences with and without the project. It should compare the net present value of all the costs and all the benefits associated with the project throughout its life time and the distribution among societal groups of costs and benefits - who pays and who gains. It may also identify alternatives to the proposed project, as well as the "no-action" alternative.

In this way EIA is generally considered as an important instrument for the prevention of environmental effects of major projects. This has also been recognised both by Hungary and Slovakia.

It was however only in June 1993 that the Hungarian Government issued its EIA Decree (No. 86-1993 VI.4) for Provisional Regulation of the Assessment of Environmental Impact of Certain Activities. This represents a turning point in the history of Hungarian EIA regulation since the decree established the framework for systematic investigation of a broad range of activities and linked it to the decision-making process (Radnia, 1993).

Also in Slovakia the need for EIA procedures was documented. The National Report of the Czech and Slovak Federal Republic to UNCED (1992) points to the following elements:

> – "During the last forty years there were no effective legislature measures to stop or at least limit the impact of unfavourable development in our country. Where few did exist, their distorted application rendered them ineffective." (page 118)

> – "A system for evaluating the environmental impacts of constructions, technologies and products is an important means of preventing pollution which has been successfully employed in advanced western countries, but it has not been fully implemented in our country." (page 119)

The need for a proper EIA in relation to the G/N project was, for example, demonstrated in a PHARE programme request on behalf on the Federal Committee for the Environment and the Slovak Ministry of Water and Forest Resources and Wood Manufacturing Industry (1990). In this project proposal, of which the cost was estimated at three million ECU, it is stated that the "strategic position of this Danubian lowland and the new large hydropower scheme under completion, 'Gabčíkovo', require a thorough and complex study of a proper impact assessment model, enabling authorities to ensure the protection of natural and anthropic resources, balanced ecological development, as well as optimised decision making and management."

The situation changed in the same year when the Federal Act on the Environment No. 17/1992 was adopted. This Environmental Act is concerned with environmental impact assessment and also with activities when they have consequences exceeding state boundaries.

National legislative developments must also be evaluated in conjunction with the evolution of international environmental regulations. The main elements in this context are:

> – the Rio Declaration on Environment and Development which mandates EIA for proposed activities that are likely to have a significant adverse impact on the environment (1992);

> – the UN Convention on Environmental Impact Assessment in a Transboundary Context (1991) which in its Appendix I mentions explicitly large dams and reservoirs as activities subject to a mandatory EIS as provided for in the Convention;

> – the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Helsinki, 1992);

> – the Convention on Co-operation for the Protection and Sustainable Use of the Danube River (Sofia, 1994).

It is evident that both Hungary and Slovakia eventually felt the need for a proper and in depth EIA on the G/N Project. The lack however of a formal legal framework before 1992 coinciding with the EIA concept as outlined in this section may explain why no EIS was ever done.

7.2 THE EVOLUTION OF EIA

7.2.1 EVOLUTION IN PROJECT EVALUATION TECHNIQUES

EIA is a project evaluation technique. Project evaluation techniques have evolved over the years, especially during the period 1970-1990. Trends in project evaluation during this time can be summarised as follows:

–before 1970

Mostly analytical techniques were used. These were very close to economic and technological feasibility studies. In these studies there was only limited attention to efficiency criteria and safety concerns. There was no possibility of public debate.

–around 1970

Mostly cost-benefit analysis with multiple aims was used. The systematic counting of advantages and disadvantages and their geographic distribution was stressed. Project evaluation was organised through planning, programming and budget control. There was no attention to environmental and social consequences of a project.

–1970 - 1975

EIA was introduced and focused on the description and prediction of ecological changes and modifications in land use. EIA also introduced public participation in the project evaluation. Attention is paid to surveillance of the project and to mitigating measures.

–1975 - 1980

Multi-dimensional EIA is encouraged – it includes among other things the reporting of impacts at the social level (social impact assessment). Public participation now becomes a fully integrated part of the project evaluation. More attention also goes to risk analysis of dangerous installations.

–1980 - 1990

EIA is no longer considered an isolated event. It is closely linked with higher level policy planning and the implementation management phases. Monitoring, post-project analysis and process-evaluation are stressed. The need for a scoping phase is recognised. More attention goes to health aspects.

The main components of present EIA systems in most countries (applicable at all levels of planning) is given by Wathern (1992) in *Figure 1*.

This evolution in aims, targets and content of EIA and EIS is reflected in national and international regulations. Main steps in this process are:

– the National Environmental Policy Act in the US (1969), which has been under constant substantial evolution (Blumm, 1988)

– the Environmental Assessment and Review Process in Canada (1973) which was updated by the Canadian Environmental Assessment Act (1992) (Couch, 1991)

– the EC Directive 85/337 (1985)

– the Resolution of the CPSU Central Committee and the USSR Council of Ministers of December 28th No. 898 (1972) which was further elaborated in the Resolution of the CPSU Central Committee and USSR Council of Ministers of 7 January 1988, No. 32 (1988) (Govorusko, 1990)

– In 1990 these regulations were completed with elements of international law e.g., the Rio Declaration (1992), the Conventions of Espoo (1991), Helsinki (1992) and Sofia (1993).

Practice in this respect has also been influenced by the role of international organisations such as the World Bank, the International Union for the Conservation of Nature and the United Nations Environmental Program.

This analysis of main trends and their legal basis shows that the aims and outcomes of EIS have changed substantially during the last 20 years. From basic analytical, descriptive studies, the requirements evolved into a complex and contextual instrument, assuring a maximum of relevant elements allowing a decision in which environmental quality can have its legitimate place.

Table 7.1: *Overview of the evolution of EIA procedures in the US, Canada, the EEC and the World Bank.*

U.S.A.	**1970** introduction NEPA	**1971** courts take active role in quality control	**1976** EIA for programmes and policies	**1978** introduction CEQ regulations/ strengthening scoping process, public participation and justification of decisions taken by the authorities		**1990s** changes are proposed to improve alternatives, global env. impacts, public participation, monitoring and the application of NEPA abroad
Canada		**1973** introduction EARP		**1979** the mechanics of the process are definitively outlined	**1984** *systematic procedures for screening and monitoring are introduced, social effects should be studied, quality control by Panel is improved*	**1990s** EIA regulations become *legally binding, the* CEAA is introduced
E.C.					**1985** EC Directive 85/337 is *introduced*	**1990s** aspects to be improved in a number of Member States: scoping, quality control; public participation, rules for studying transboundary impacts
World Bank				**1984** a policy statement is issued requiring that env. considerations are taken into account	**1989** introduction of Operational Directive on EIA (OD 4.00, Annex A)	**1991** screening, public consultation and quality control mechanisms are improved

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7.2.2 EVOLUTION IN EIA PROCEDURES

A distinct evolution in EIA procedures can be distinguished for the period pre 1970-1993. As shown in *Table 7.1*, it is, however, not possible to identify clearly marked years in which certain changes were made in all countries or institutions at once. Each country or institution introduced EIA at its own time. Once EIA is operational shortcomings become obvious within a few years resulting in the adoption of amendments.

Canada and the World Bank first tried to introduce EIA as a policy which was not binding. Both of them realised that more stringent rules were necessary. In all places the need for clearly outlined EIA procedures becomes evident after a few years of EIA practice. Screening, scoping, public participation, quality control and monitoring were steps in the EIA process which needed improvement or special attention in the pre 1970-1993 period and will continue to be important in improving EIA in the future.

The historic evolution of "EIA state-of-the-art" can be broadly subdivided into three decades:

−1970s: high hopes and experimentation

The 1970s was the period of high hopes and experimentation. EIA was thought to be a very powerful instrument which would introduce objective scientific knowledge into the decision-making, resulting in a more environmentally friendly, efficient and open management of human activities on earth. The first reports were prepared, experience was gained, positive and negative aspects of the approach were identified.

−1980s: realism, expansion and new procedural steps

In the 1980s it became very clear that EIA as it was applied in the 1970s would not solve society's environmental problems. EIA can only be effective in case that all parties involved are willing to co-operate in the event that the environmental consequences of policies, plans and programmes are taken into account, in the case that "environment" is defined to include social aspects, cumulative effects, etc. Although it is clear that EIA has its limitations, it was introduced for the first time in the 1980s in many countries outside North America. New procedural steps to make EIA more effective are tried out: screening, scoping, justification of decisions, quality control and monitoring are introduced.

−1990s: establishment of new procedural steps and legislation, unresolved problems

In the 1990s the need and function of procedural steps such as screening, scoping, justification of decisions, public participation, quality control and monitoring are recognised. It becomes clear that the dramatic changes which EIA causes in the decision-making process can only be introduced by way of legislation and detailed, transparent and verifiable procedures. It becomes clear that EIA is still not solving our environmental problems: the prediction of cumulative impacts and the introduction of EIA for policies, plans and programmes remain largely unresolved.

This background highlights also that in 1977, when the G/N treaty was signed between Czechoslovakia and Hungary, not only clear-cut EIA procedure existed, but moreover the period can be characterised as very experimental from an EIA point of view. In 1989, however, when the treaty was given up, it was clear that a proper, complex and refined procedure was able to provide a realistic basis for decision making. In the 1990s there was, also on the basis of existing national and international regulations, no justification for implementing Variant C without an EIA as defined in a contemporary context.

7.2.3 EVOLUTION IN THE CONTENTS OF EIS'S

Like EIA procedures the contents of EISs are also undergoing changes as more and more experience is gained in the EIA of different sectors. Despite minor differences throughout the world, there is a general consensus on the content of an EIS.

Before 1977 it was not clear for many proponents or authorities what information should be included in an EIS. This was due to a lack of experience, but has changed since 1978, when the US Council on Environmental Quality (CEQ) first issued regulations which gives more detailed guidelines on the content of EISs. The Council periodically publishes procedural guidelines and requires that each Federal agency publish its own guidelines in response. There is provision for revision of the guidelines at appropriate periods in the light of experience with the system's operation and recent advances in EIA methodology. These guidelines, and similar ones adopted in other countries, have assisted in the development of a broad consensus on EIS standards.

Contents of EISs in the US

It is the responsibility of the proposing agency to prepare the EIS. According to regulations in the US, for example, an EIS must contain the following (Munn, 1989):

1. Description of the proposed action; statement of purposes; description of the environment affected;

2. Relationship to land-use plans, policies, and controls for the affected area;

3. Probable impact-positive and negative; secondary or indirect, as well as primary and direct; international environmental implications;

4. Consideration of alternatives;

5. Probable adverse effects which cannot be avoided;

6. Relationship between local and short-term uses and long-term environmental considerations;

7. Irreversible and irretrievable commitment of resources;

8. Description of what other Federal considerations offset adverse environmental effects of proposed action and relation of these to alternatives.

In addition, the comments received from reviewers must be attached. This is the general requirement for all types of development projects including the water resource projects.

Contents of EISs in Canada

In Canada the EIS is a detailed documented assessment of the environmental consequences associated with the project prepared in accordance with the guidelines issued by the Environmental Assessment panel (expert body formed for specific projects). The type of detailed information required is determined by the nature and location of the project.

Contents of EISs in Japan

In Japan (Barrett and Therivel, 1991) the draft EIS should cover similar items like those in the U.S. Surveys and studies, prediction and evaluation mentioned should be conducted in accordance with guidelines which should be established for each category of relevant projects by the competent minister in consultations with the Director-General of the Environmental Agency. The final EIS should cover:

1. the contents of the draft EIS as explained above;

2. a summary of the comments received from the residents of the related area;

3. comments of the prefectural governor with jurisdiction over the related area;

4. views of the project undertaken on the comments received from the residents and prefectural governor.

Assessment of both the social environment (safety and amenity of communities, cost/benefit for individuals and the public including employment, income, population density, consumption, land-use pattern, industrial structure, finance, and public service etc.) and the natural environment (quality and quantity of natural features, pollution, disaster) are considered. These are determined through field surveys.

Contents of EISs in the European Communities

The EC Directive 85/337 requires Member States to include the following aspects in the EIS: a description of the likely significant effects on the environment, direct and indirect, of the development with reference to human beings, flora, fauna, soil, water, air, climate, the landscape, the interaction between any of the foregoing, material assets, the cultural heritage. A summary in non-technical language of the information specified above should also be included (Lee and Colley, 1990). Next to the aspects considered above, the European Communities EIA directive requires proponents to highlight areas of uncertainty by indicating 'technical deficiencies or lack of know-how' encountered in compiling information included in an environmental assessment (Council of the EC, 1985).

Contents of EISs in the USSR and Central and Eastern European Countries

In the former USSR forecasting practice to predict environmental implications for implementing the electrification plan in Russia was already existing in the 1920s, although this experience was not further developed or applied during the following years. The USSR returned to the idea of systematic environmental impact study of projects again in 1972, and this was made instrumentally more detailed in 1988. In a 1990 evaluation, Govorushko concludes that there were considerable difficulties in implementing EIA in the Soviet Union: lack of procedures considering regional and social specifications, acute deficits in numbers of specialists, etc.

In the Eastern European countries the central planning system provides a coherent framework for EIAs. In the 1980s the Council for Mutual Economic Assistance (CMEA which included Hungary, Bulgaria, Cuba, Czechoslovakia, GDR, Mongolia, Poland, Romania, and USSR) required the assessment to include several phases and to be technological, bio-medical, economic, or social, the latter being the most comprehensive. General systems include the natural environment, the man-made environment and socio-economic activities.

The overall picture which emerges is that the most influential country in the region paid attention to EIS, but that their content had no influence on the outcome of the decision record.

Contents of EIS in Slovakia

According to Annex 2 of the Environmental Act (17/1992), which is fully in force into both the Czech Republic and the Slovak Republic, the documentation and the EIA of projects must contain the following elements:

a) a description of planned activity and its objective;

b) a description and assessment of adequate and justifiable variants of the project, the ecologically optimum variant;

c) a description of the environment likely to be significantly influenced by the project or its variants;

d) a description of assumed environmental impact of the project or its proposed variants and an estimate of their significance (not only assumed direct impacts, but also indirect, secondary, cumulative, synergic, short-term, long-term and permanent effects). This includes the impact on the population (health hazards, social consequences, economic consequences), effect on ecosystems, their components and functions, effect on anthropogenic systems, their components and links, effect on the structure and exploitation of the land)including the effect on the aesthetic quality of the landscape), and large-scale influence of the project on the landscape, i.e., an assessment of the ecological carrying capacity of the territory;

e) a description of the measures proposed for the prevention, elimination, minimisation and/or compensation for the environmental impact of the proposed variants of the project.

According to Annex 4 to the Environmental Act the environmental impact assessment of projects which affect areas beyond the State border must contain at least:

a) a description of the planned activity and its objectives;

b) a description of reasonable alternatives to the planned activity;

c) a description of the environmental component likely to be substantially influenced by the planned activity or its alternative variants;

d) a description and assessment of the possible impacts of the planned activity and any alternative variants on the environment;

e) a description of the measures intended to minimise the scope of the adverse influence on the environment;

f) a specification of concrete forecasting methods and assumptions upon which the measures are based and the corresponding environmental data used, etc.

The scope of the environmental impact assessment must be discussed by the appropriate assessment authorities of the State administration authorities concerned, with the communities the territories which are affected by the impact of the project, and with the public.

Contents of EIS according to the Espoo Convention:

Information to be included in the environmental impact assessment documentation shall, as a minimum, contain, in accordance with Article 4:

a) a description of the proposed activity and its purpose;

b) a description, where appropriate, of reasonable alternatives (for example, locational or technological) to the proposed activity and also the no-action alternative;

c) a description of the environment likely to be significantly affected by the proposed activity and its alternatives;

d) a description of the potential environmental impact of the proposed activity and its alternatives and an estimation of its significance;

e) a description of mitigation measures to keep adverse environmental impact to a minimum;

f) An explicit indication of predictive methods and underlying assumptions in compiling the required information;

g) an identification of gaps in knowledge and uncertainties encountered in compiling the required information;

h) where appropriate, an outline for monitoring and management programmes and any plans for post-project analysis; and

i) a non-technical summary including a visual presentation as appropriate (maps, graphs, etc.).

Although the content of EIS varies among countries and over a period of almost 20 years, there is a clear idea of what an EIS should contain consistent with the aims of the EIA procedure since the period 1975-1985. Moreover, as the main lines of contents are written down in national and international agreements since the 1990s, there can be no doubt about the minimum requirements for the content of an EIS.

The quality of EIS depends on the level of technical sophistication, consistency in terms of coverage of topics, executive summaries, clearly organised sections, objective orientation, adequate project description, sufficient analysis of all topics, consideration for public input and participation in planning and review processes (Kim and Murabayashi, 1992).

7.3 SUSTAINABLE DEVELOPMENT AND EIA

7.3.1 THE CONCEPT OF SUSTAINABLE DEVELOPMENT

The World Commission for Environment and Development (WCED) defined Sustainable Development (SD) in ethical, social and economic terms as the new path of economic and social progress that "meet the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). SD is a strategy for the development of the quality of life of people based on the maintenance of three forms of capital (man made, human and natural capital). Sustainability is defined as the 'indefinite survival of human species (with a quality of life beyond mere biological survival) through the maintenance of basic life support systems (air, water, land, biota) and the existence of infrastructure and institutions which distribute and protect the components of these systems' (Liverman *et al.,* 1988). Environmental sustainability refers to natural capital which is a stock of environmentally provided assets which results in a flow of useful goods and services. Sustainability depends on interaction of economic changes with social, cultural and ecological transformations.

Translation of the concept into practice is still a very difficult task. The concept has, however, proven useful, in raising awareness of environmental and social concerns in economic development planning and decision-making.

7.3.2 LINKING SUSTAINABLE DEVELOPMENT AND EIA

Sustainable development is a unifying concept which consists of ecological, economic and the social aspects of welfare of present and future generations. EIA is one of the most useful tools for checking the development activities for environmental, economic and social sustainability. It helps to integrate environmental and social concerns of a project/policy at an early stage without stopping economic development in its tracks. EIA has the potential to check the integration of the three vital components of the sustainable development equation i.e. environmental, social and economic issues in the development decision-making process. Dalal-Clayton (1992) argues that the achievement of sustainable development requires, inter alia, the development of a framework of an appropriate 'tool' to aid project, programme and policy development and implementation. A modified EIA process can effectively include social, participatory and economic issues in order to address the key links between environmental impact and sustainable development.

Sustainable development depends on sustainable use of resources. EIA assists sustainable economic development (Carpenter and Maragos, 1989):

- EIA points out both the dangers to environmental values and the opportunities to use these resources;

– EIA is a constructive pro-development tool for management that improves the success and lengthens the life of projects;

– EIA quantifies the factors making up sustainability and predicts the future productivity of the landscape (e.g. in mining);

– EIA specifically treats the risks to human health from technologies and urbanisation accompanying development;

– EIA is concerned with biological diversity and the aesthetic and recreational values of intact natural systems;

– the surveys and inventories conducted as part of EIA may reveal unexpected natural resource values.

SD has broad social, economic and environmental objectives for survival and improvement of quality of life of all human beings in present and future generations (*Figure 2.1*). EIA can help and support the attainment of most of the objectives. It allows public participation, is pro-development and hence helps economic growth and poverty alleviation. At the same time social justice for the affected population is discussed. EIA assesses the social impact of the development activity and takes note of the disturbance to the social cohesion. It supports the use of cost effective technology and of optimal siting for development projects and hence supports efficiency. EIA is an important tool to achieve certain environmental objectives like ecosystem integrity, conservation of biodiversity, carrying capacity and climate stability.

EIA is an important tool to achieve conditions for SD (i.e., 'the strategic imperatives for SD' put forward by WCED) as shown in *Figure 3*.

All the international attempts for SD have highlighted the importance of EIA as an efficient tool for achieving the SD goals. Sustainable development as an idea had been espoused in the World Conservation Strategy (WCS) in 1980, which recommends advance assessment of the likely environmental effects of all major actions as a priority national action (IUCN, 1980). The Brundtland Report "Our Common Future" (WCED, 1987) which made the concept of Sustainable Development popular recommends to undertake, or require prior assessments to ensure that major new policies, projects and technologies contribute to sustainable development (WCED, 1987). The Earth Summit at Rio in 1992 which set the planet on a new course toward global sustainable development, also stressed the importance of EIA in sustainable development. Principle 17 of the Rio Declaration states: "EIA, as a national instrument, shall be undertaken for proposed activities that are likely to have a significant adverse impact on environment and are subject to a decision of a competent national authority"(Johnson, 1993). Different chapters of Agenda 21 highlight the need for making sure that environmental concerns are duly taken into account in development planning.

7.4 TRENDS OF INTERNATIONAL DECISION-MAKING ON DAMS

Despite the evidence of social and environmental damage, large dam building is an ongoing enterprise in many parts of the world. Large dams are generally projected as sources of clean energy and water supply by their proponents, but have been criticised on grounds of social unacceptability, environmental unsustainability and economic inviolability all over the world.

The history of environmental consideration in large dam decision-making in different countries can be divided into three stages: the pre EIA, early EIA and current EIA procedure periods. Many countries have sector specific guidelines for EIA, but major steps in EIA procedures are similar.

The environmental considerations in large dam project planning and decision-making in the various periods are analysed here through a literature survey and through case studies of large dams in each period. Large dam projects prepared in the pre-EIA period resulted in major impacts as a result of not considering environmental aspects. These projects show the importance of proper EIA in project planning and implementation. The EIA procedures during the early EIA period show the inadequacies in EIA application. During the early EIA period, EIA was imposed on the ongoing project planning and implementation necessitated by the new legislation of environmental consideration in project planning. The current EIA period shows more or less proper EIA procedures in at least some of the countries. Even though EIA has been started at different times in different countries, the trend of evolution is similar everywhere. In particular, all large dams financed by the World Bank are subject to an EIA.

7.5 LACK OF EIA ON THE GNB PROJECT

7.5.1 HUNGARY

Historical Context

The EIA situation in Hungary in the pre 1970-1993 period is not clear-cut. It is, however, safe to say that there was no well established EIA procedure or legislation in Hungary in the pre 1970-1993 period. Several sources confirm that the need for EIA was felt for the first time as a result of the Gabčíkovo-Nagymaros controversy. EISs prepared on the GNBS, in other words, did not follow one clear and obvious EIA procedure, but were prepared on an *ad hoc* basis.

The EIA adoption process started in 1983 with the resolution of the National Council on Environmental Protection. It was followed by a decree which made it obligatory to undertake impact studies for major projects under governmental control. This decree was repealed in 1989 (Radnia, 1993). In 1992 Bochniarz stressed the importance of EIA in Hungarian environmental legislation: "Hungarian legislation

should give particular attention to EC Directive 85/337 and the IUCN draft convention regarding EIA..."

It was only in June 1993 that the Hungarian Government issued its EIA Decree (No. 86/1993 (VI.4) for Provisional Regulation of the Assessment of Environmental Impact of Certain Activities). This represents a turning point in the history of Hungarian EIA regulation since the decree established systematic investigation of a broad range of activities and linked it to the decision-making process (Radnia, 1993).

In conclusion, it is possible to situate the two Hungarian studies on the GNBS in the historic framework developed in previous sections. It is clear that Hungary is only today in the stage of developing EIA procedures and legislation, comparable with the 1970s period in the US and the 1980s period in the European Communities. The preparation of the Gabčíkovo-Nagymaros environmental documents (1983, 1985) can be placed into the early EIA period, which means that these studies were imposed on the project which was, at that time, in an advanced planning stage, and construction was already started.

Since Hungary did not have any prior experience with EIA and did not incorporate a systematic screening of environmental impacts into its legislation, the Gabčíkovo-Nagymaros EISs can be considered "experiments". There was no previous experience, no established procedures or guidelines and no EIA traditions to form a basis for the preparation of environmental reports of high quality.

At the time that the Gabčíkovo-Nagymaros environmental documents were prepared, the necessary information and expertise to prepare high quality EISs for large dam projects was available in other countries, e.g. in North America. It should, however, be taken into account that Hungary was still part of the former Eastern Europe Communist Bloc during the mid-1980s and that scientists and decision-makers will have looked to the USSR for expertise and not to the US or Canada.

Hungarian Study of April 30th, 1983

The document of 1983 states that it is not a full EIS and that a complete impact study can be expected within two years. The document only gives an overview of the conclusions from earlier investigations. In Chapter 4 only the predictable impacts are examined, only ecological impacts are considered and these are only partly considered. The material does not contain any figures or tables (except one map from the region). There are no references used in the text.

Hungarian Study of June 1985

This 1985 study is the most comprehensive when compared to the 1983 and 1993 document. In fact, it is the only document which can be called an EIS. The other two documents are too incomplete to be given the name "EIS".

The 1985 report has been examined in two different ways: first it has been subjected to the Lee and Colley review package (1990) and second it has been checked to what degree the report conforms with a checklist developed for the quality review of EISs for dam projects.

The Lee and Colley review package (1990) consists of a list of review topics, a list of assessment symbols and a collation sheet. Two reviewers have to check the quality of the EIS independently and compare their results. If major differences in assessment occur the two reviewers should come together and discuss the problematic topics. The list of review topics is divided in four major parts: description of the development, the local environment and the baseline conditions; identification and evaluation of key impacts; alternatives and mitigation; and communication of results.

The Gabčikovo-Nagymaros EIS prepared in 1985 contains parts which are well intentioned. The whole must, however, be considered as unsatisfactory because of omissions and inadequacies.

The major limitations of this document can be summarised as follows:

- there is no discussion on the scope of the document: why have certain aspects been studied and others not?

- although a lot of background studies have been made for the proposed project, these studies are not discussed in an integrated way in the main body of the text;

- although alternatives and mitigation measures have been proposed in the EIS, they are not the "heart" of the document. Alternatives and mitigation measures are limited and not studied in sufficient detail;

- although impacts are examined, it is not discussed what was the basis for the interpretation of the data. The choice of standards, assumptions and value systems used is not explained;

- the communication of the results is insufficient. The layout is confusing, the reference system is not correct and reviewers have doubts about the objectivity of the study.

The EIS should be a document which allows anyone who is interested in the proposal to learn in a short period of time what the project is about, what the possible impacts will be, what alternatives and mitigation measures are available to reduce adverse effects and what the local and general population think about it. The EIS in question does not fulfil these requirements: the document is rather confusing and leaves the reader with a lot of questions.

7.5.2 CZECHOSLOVAKIA

Historical Context

It is not easy to reconstruct the status of EIA in Czechoslovakia in the period before 1992, when the Environmental Act was adopted. A number of elements are, however, relevant:

— The USSR as a leading *country in the area* engaged in its first examination as early as the 1920s and in a more systematic way since 1972. Although specific logistic structures were set up since 1988, the process was characterised by many difficulties (Govorushko, 1990).

— The SM states that "environmental impact had been carefully studied by both parties to the 1977 Treaty both before and after the conclusion of the Treaty" (para 1.118). The SM claims that the Bioproject and its 1986 update was thorough, stating that "these studies showed that the Project was sustainable in environmental terms" (paras 1.4 and 1.22). In the context of the evolution of EIA, these quotes are testimony to a profound belief in the capacity of analytical descriptive studies as a substitute for the whole process, with its complex content. Scientifically *this* is an example of overestimation of the power of analytical descriptive studies, at a moment when the contextual limitations were already established.

— The internal legal situation is most clear with the Environmental Act in 1992.

Bioproject and Other Czechoslovakian Studies

It was not possible to examine the Slovak documentation in the same way as the Hungarian document because no Slovak documents in the format of EISs were provided.

To analyse the relevant material mentioned in the SM, these studies which "showed that the Project was sustainable in environmental terms" (para 2.24) and which "demonstrated to the satisfaction of the parties that the Project would not affect surface or ground water in an unacceptably negative way and, to the contrary, would lead to certain specific improvements in water quality" (para 2.15) were asked for by the "Note Verbale" of June 1994. The last letter was a reply to a letter of 3 August 1994 in which Dr. Tomka, the Agent of the Slovak Republic, states: "These two Annexes are adduced in support of contention that the [Project] was indeed very carefully researched. This contention does not relate to the individual findings of specific reports, but to the fact of their existence. The actual contents of the reports were not relevant to the contention and there is therefore no need to annex the

reports." From a scientific point of view it is, however, impossible to evaluate sustainability without knowing the content, scope and conclusions of the studies showing and discussing these elements.

It is not clear to what degree the seven mitigation measures discussed on pages 52 and 53 of the Slovak Memorial are developed in detail in the Bioproject and its 1986 update.

With the information available it is not possible to evaluate the Bioproject making use of the evaluation instruments (lists of review topics).

Studies which were completed between 1974 and 1990 summarised in Annex 24 of the Slovak Memorial tackle the following subjects:

	number
construction	. 13
design, general arrangement and lay-out (technical)	48
economical considerations	2
effects on Austria	2
effects on drinking water supply	1
energetic aspects	1
forest ecosystems	1
groundwater	3
hydrology	22
ice discharging	2
location alternatives	5
monitoring of GN project	2
navigation	5
operation of the project	2
power transmission lines	2
protection measures	6
summary documentation	1
water quality	1

Based on the summaries included in Annex 24 it seems that the majority of the 118 studies mentioned focus on technical aspects of general design, construction and the hydrological regime of the Danube river. It is not clear if environmental aspects have been taken into account in these reports.

Eleven studies (on forest ecosystems, groundwater, location alternatives, protection measures and water quality) are clearly related to topics which should be included in an environmental impact assessment.

7.5.3 REALISATION OF HUNGARY AND CZECHOSLOVAKIA THAT NO EIS WAS EVER PERFORMED

Both Hungary and Slovakia initiated their EIA laws in the early 1990s. At that moment both countries were more conscious about the value of the procedure and were concerned to establish a content requirement which was in agreement with the international state of the art.

The analysis provided in this chapter shows that Hungary concluded correctly when it suspended the construction in Nagymaros in May 1989 and at Dunakiliti in July 1989, calling for a joint comprehensive EIS. The country seemed to be fully aware of the fact that no proper EIS had ever been performed.

Also Slovakia implicitly and explicitly recognised the lack of a proper EIS. Implicitly because of the overestimation of the value of analytical descriptive studies (which were not made accessible for evaluation of their content). Explicitly because of the 1990 project proposal which should result in a "proper impact assessment model" for the Danube and its water resources.

7.6 CONCLUSIONS

It can be concluded that EIA is not static, but a learning process which is continuously in evolution. Not only the EIA procedures and EIA process but also the contents of the EIS have changed over time. The most recent trend focuses on the link between EIA and sustainable development, both generally and specifically in terms of dams.

Based on the information available to the researchers it can be concluded that the Gabčíkovo-Nagymaros environmental documents are early EIA period pieces. Although EIA procedures were well advanced in many countries around the globe in the mid 1980s Hungary did not yet have a tradition of introducing environmental concerns into its decision-making. It was only as a result of public controversy in relation to the Gabčíkovo-Nagymaros project that the need for EIA became clear and that an EIA was imposed on the proposed project. A literature review revealed that EISs prepared in an early EIA period most often do not result in high quality documents.

Research also indicates that the presence of a well established EIA procedure is one of the major requirements for EIA to be successful. Since an EIA procedure was only formally established in Hungary with the introduction of an EIA decree in 1993, the Gabčíkovo-Nagymaros environmental documents were not prepared in optimal conditions.

The two environmental documents prepared in Hungary which were examined cannot be considered satisfactory. The 1983 report does not satisfy the basic

requirements and should not be given the name EIS. The 1985 report is an EIS which has a number of defects. The documents prepared in Czechoslovakia also appear unsatisfactory.

The general conclusions are:

– although EIA procedures and contents are continuously being improved as a result of experience gained, there have not been major changes or significant developments in the state of the art of EIA during the 1980s;

– although EIA was not yet introduced in all countries by the end of the 1980s, it was generally available as an instrument for environmental protection. At the end of the 1980s it was generally accepted that large infrastructure projects might cause substantial environmental effects and that EIA can be used to detect and mitigate adverse effects;

– no true EIS has ever been done on GNBS;

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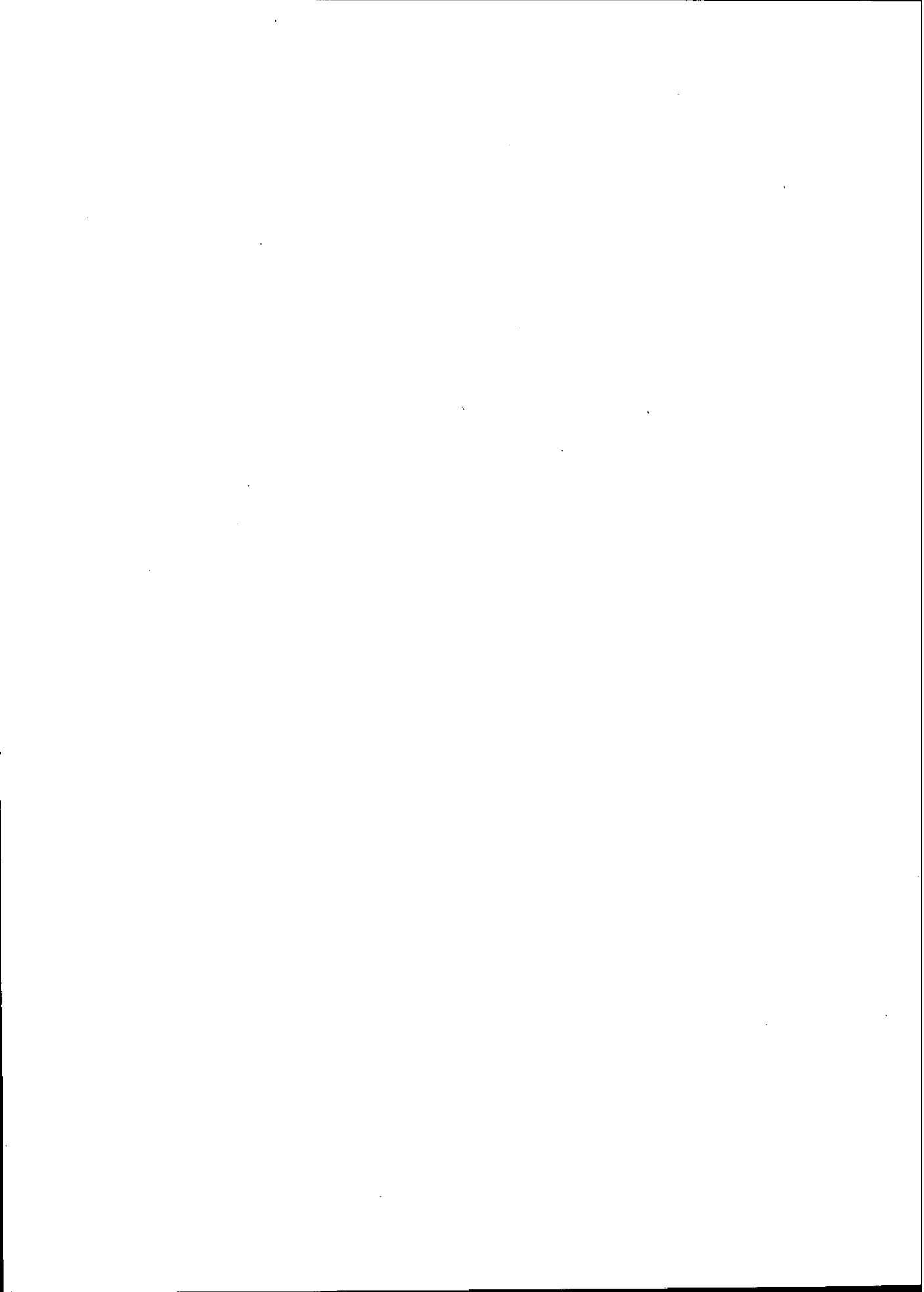43 Bd du 11 Novembre 1918, F-69622 Villeurbanne Cedex, France

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